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ALTERNATE SPACE SHUTTLE CONCEPTS MID-TERM REPORT

Volume II — Concept Definition, Planning and Cost Data
Part III — Cost Data

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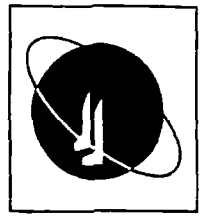

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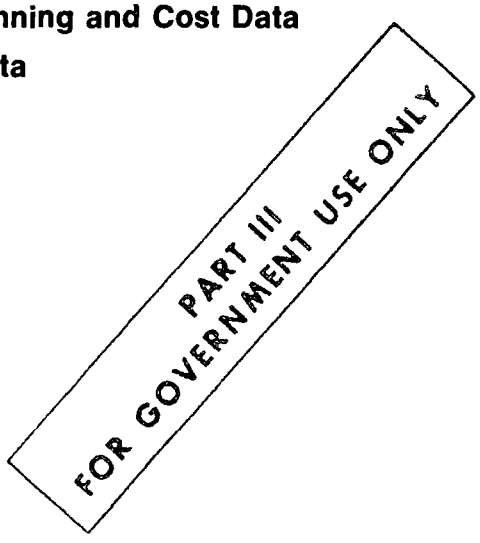

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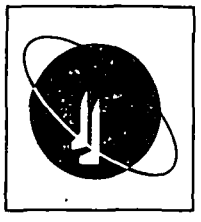

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PREFACE

This mid-term report on Alternate Space Shuttle Concepts is submitted in accordance with DRD requirements and is organized as follows

Volume I – Executive Summary
Volume II – Concept Definition, Planning and Cost Data
Part I – Concept Analysis and Definition
- *Appendix A – Structural Descriptions, Loads and Analyses*
- *Appendix B – Aerodynamic and Thermal Analyses*
- *Appendix C – Materials and Thermal Protection System*
- *Appendix D – Propulsion*
- *Appendix E – Environmental Control and Life Support (ECLS) Subsystem Studies*
- *Appendix F – Crew and Passenger Accommodations*
- *Appendix G – Integrated Avionics*
- *Appendix H – Power*
- *Appendix I – Reliability and Maintainability*
- *Appendix J – Safety*
- *Appendix K – Trajectory, Guidance and Control Analyses*
- *Appendix L – Orbiter Self-Ferry*
- *Appendix M – Mass Properties*
- *Appendix N – Cryogenic Studies*
- *Appendix O – Mechanical Systems*

Part II – Program Planning Data
Part III – Cost Data
- *Appendix P – Orbiter/Booster Heatsink-Radiative TPS*
- *Appendix Q – Design/Cost Performance Management System*

Volume I of this report is a brief summary of the results to date, and contains the concept comparisons and conclusions for continuing the study Volume II, Part I summarizes the work completed on the vehicle configurations, emphasizing the most promising configuration(s) in each concept. Data which are relatively common to all concepts, such as avionics and power, plus additional detailed backup data are presented in the appendices Volume II, Part II contains development, test and operations requirements and planning data

STUDY PARTICIPATION

The study of Alternate Space Shuttle Concepts reported herein was conducted jointly by the Grumman Aerospace Corporation, the Boeing Company and their associates. To assure consistency of results, Grumman and Boeing worked closely together, particularly in the areas of costing and concept evaluation and comparison. In general, Grumman concentrated on overall study management, orbiter design, analysis of mated configurations and development test planning. Boeing concentrated on booster and drop tank design and ground operations and maintenance planning. The other team associates and their major areas of participation are shown below:

GRUMMAN	• Systems Manager • Orbiter
BOEING	• Booster • Operations
AEROJET GENERAL	• Cryogenic Tankage
AVCO	• Thermal Protection Systems
AVIONS MARCEL DASSAULT	• Thermal Protection Systems • Insulation Systems
DORNIER	• Subsystem Technology
EASTERN	• Operations • Maintenance
GE	• Avionics
NORTHROP	• Orbiter Technology

Many other organizations contributed significantly to the data presented in these volumes. Particular appreciation is extended to the Denver Division of the Martin Marietta Company, United Technology Center and Pratt & Whitney Divisions of United Aircraft Corporation, Thiokol Chemical Corporation, Aerojet Solid and Liquid Propulsion Company, Lockheed Propulsion Company, Rocketdyne Division of North American Rockwell Corporation and TRW Corporation for their help in achieving the technical and cost credibility which we feel this report represents.

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INTRODUCTION

THE ALTERNATE SPACE SHUTTLE CONCEPT STUDY

Two Phase B Program Definition studies of a fully reusable, two-stage-to-orbit space shuttle have been initiated by NASA. Their objective is to define a low-cost system to transport payloads between the earth's surface and low earth orbit during the late 1970's and 1980's. In addition, to assure that the optimum earth-to-orbit logistic system is selected, NASA has initiated the study described in this report to investigate several promising alternate concepts. The Grumman Aerospace Corporation and its Associate Contractors undertook this study for NASA in July, 1970 under contract NAS9-11160. This mid-term report documents the effort on the study to December, 1970.

OBJECTIVES

To achieve a low-cost space transportation system and other objectives, the following program characteristics have been identified by NASA:

- A significant reduction below present operating costs.
- Flexibility for a variety of payloads and missions.
- Transport for passengers and cargo approximating airline type operations as a goal.
- A fully or partially reusable system with a high launch rate. Short turnaround and reaction times compatible with rescue missions.

NASA has further defined the fundamental objectives of the study as follows:

- To define alternate space shuttle systems
- To accomplish conceptual designs of the alternate space shuttle systems and define the total program for each alternative. The system studies will stress areas such as structure, aerodynamics, thermal control, propulsion and electro-mechanical systems. Information on subsystems such as avionics, environmental control, and electrical power (including APU's) will be furnished by NASA to the extent available from existing in-house studies and certain trade studies performed by the Phase B contractors.

- To obtain an understanding of the scope, schedule and cost of the alternate space shuttle systems and to perform comparative analyses among them.
- To obtain an understanding of the supporting research and technology which must be accomplished to carry each of the alternates forward.

The three basic concepts being examined are as follows:

- Concept A - Stage and One-Half - This concept encompasses a single manned spacecraft with an on-board cryogenic propulsion system and drop tanks for supplementary propellants. Both expendable and recoverable drop tanks have been considered.
- Concept B - Expendable Booster With Reusable Orbiter
  - B-1 Growth System - This concept envisages a single reusable second-stage orbiter configuration to be used initially in the testing and possibly in the initial operational stages with an appropriately modified S-IC or other existing expendable booster. This program will be planned to provide for the development of a reusable first stage subsequent to or lagging the orbiter development program.
  - B-2 Operational System - This concept is similar to B-1 above except that a new minimum-cost first-stage expendable liquid or solid booster will be developed and used an as operational part of the system.
- Concept C - Reusable First Stage Utilizing the J-2S Engines and Solid Auxiliary Boosters (Throw Away Solids) with Reusable Orbiter Second Stage - This concept utilizes J-2S engines in both the booster and orbiter stages. The first-stage reusable booster may be augmented as required by solid rocket motors which are dropped following propellant depletion and not recovered. Consideration has been given to later retrofitting with high-performance rocket engines when available and eliminating the solid rocket motors.

GUIDELINES

The guidelines for this study are described in detail in the Study Control Document for the contract and in Technical Directives issued by NASA. These

documents describe the Program, System, Orbiter and Booster Requirements to be studied. These requirements are generally similar to the Phase B study requirements in most respects, including the definitions of payload weight and cargo bay size (currently 25,000 pounds and 15 feet diameter by 60 feet length). The design reference mission used was the resupply of a space station located at 270 n. mi. altitude and 55° inclination, with launch from and return to ETR. However, the major differences in the guidelines between this study and the Phase B studies are as follows:

- Configurations - As described above, this study examines alternate concepts to the fully reusable two-stage Phase B concept
- Cross Range - This study has been limited to low cross-range (200 n mi) requirements, whereas the Phase B studies include both low and high cross-range (1500 n mi) requirements
- Airbreathing Propulsion - This study has been based on the use of airbreathing engines in the booster only; the orbiter has been baselined to dead stick landings
- Subsystems - NASA has provided data describing the characteristics and cost of the avionics, power and environmental control/life support subsystems, while the Phase B Study Contractors generated their own data in these areas. The data provided to this study in these areas is based on MSC in-house studies of the "DC-3" concept.

In addition, this study has responded to the direction to minimize the impact of potential abort requirements on the initial development of configurations. In particular, the capability to abort to orbit has not been included in the orbiters described in this report. Means of providing this capability are being studied separately, and the status of these studies are reported in Appendix K.

STUDY APPROACH

The studies have been structured and phased to allow maximum NASA visibility and afford ready comparison among the three concepts. NASA has participated actively in the study and redirected the efforts as necessary. The study

has been phased to allow a comprehensive review and comparison of the technical characteristics and representative program costs at the end of the fifth month of the study.

The basic study approach to the Alternate Space Shuttle Concepts Study is depicted in Figure 1, Overall Study Flow. A two-pronged effort was undertaken in the first three months, consisting of conceptual designs of one baseline configuration for each of the three NASA-defined alternate shuttle concepts, and a parallel evaluation of candidate alternative configurations to the baseline configurations. The baseline configurations were initially used to develop more detailed definitions of weight, performance and cost. The candidate alternative configurations were reduced from many at the outset of the study to seven by the end of the sixth week and to only four by the end of the third month. The fourth and fifth month have consisted of preliminary design refinement and costing of these four configurations to permit the required comparison of the three concepts and selection of the most promising concept for further in-depth study during the sixth through eleventh months.

The definition of the concepts to be studied has been expanded over the description given previously. Configurations using strap-on solid rocket modules were added to the stage-and-one-half concept. The study of expendable boosters included the Titan family. The two-stage fully reusable concept included a configuration optimized for new high-pressure engines (rather than for initial use of J2S engines) to serve as a reference for comparing the alternate concepts with the Phase B studies.

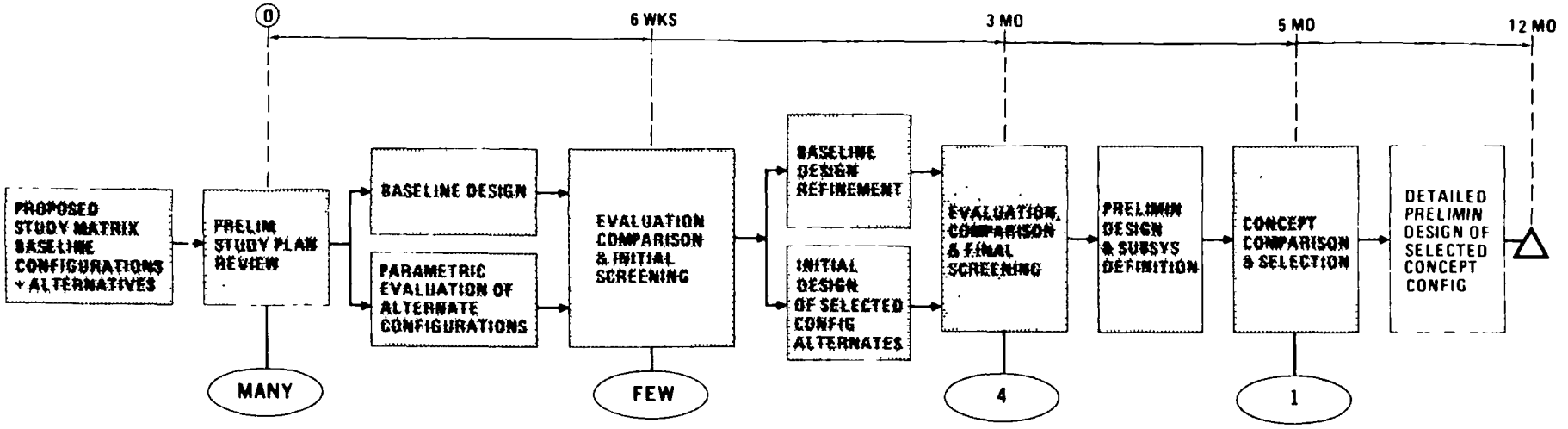


Figure 1. Study Logic

Section 1

INTRODUCTION

This part of the mid-term report contains program costs for implementing the vehicle concepts, described in Parts I and II, through Phase C/D development and the subsequent 10 years of space shuttle operations. The cost data, presented herein, has been derived from integrated Grumman-Boeing costing analyses. Grumman, as prime contractor, is responsible for defining common costing guidelines and ensuring compatibility of all derived program costs. Actual development of concept cost data was shared between the Grumman-Boeing Team. Grumman was responsible for developing all Orbiter vehicle costs, reusable Booster costs, test operations and test facility costs, and total program costs for the Stage and a-half and Reusable Orbiter/ Booster concepts. Boeing was responsible for developing all operational costs, manufacturing/production facilities and operations facilities/GSE costs, expendable strap-on hardware costs, expendable Booster costs and total program costs for the Expendable Booster/Reusable Orbiter concepts.

The remainder of this document is organized in the following manner:

- System Cost Definition
- Program Cost Description
- Concept Cost Data
- Concept Cost Comparison
- Programmatic Alternatives

Section 2 - System Cost Definition covers the basic ground rules and assumptions used for all concept costing. Individual concept development schedules plus a definition of operations traffic models and related fleet sizes are also included.

Section 3 - Program Cost Description defines the work breakdown structure, describes the parametric and cost estimating models used in the study plus the related cost estimating relationships, and test/operations estimates employed in the study. A procedure for deriving equivalent Phase B type NASA cost objectives from the results of this Phase A study is also presented.

Section 4 - Concept Cost Data contains the most recent costs for the configurations presented at the mid-term review. This section is subdivided along the three alternate space shuttle study concepts (A, B, C). Within each concept,the most recent data is presented first. This is followed by a sequential comparison of configuration costs data derived during the first half of the study. NASA DRD-MF003M Cost Forms A and D are also included for the mid-term configurations.

Section 5 - Concept Cost Comparison includes a comparative description of the selected configurations included at the mid-term review plus detailed comparison of related program costs. DDT&E costs, production and operations costs, launch costs per flight and cost sensitivities to discounting.

Section 6 - Programmatic Alternatives discusses econometrics related to phased reusable booster operations versus stretched development and delayed FMOF.

Appendices P and Q are also added to this part of the mid-term report. Appendix P summarizes the results of an Orbiter/Booster Heat Sink-Radiative TPS Cost Study. Appendix Q, in turn, describes a Cost/Design Performance Management System proposed for the second half of the study.

Section 2

SYSTEM COST DEFINITION

This section describes the basic ground rules and assumptions used to cost each program concept. These guidelines were developed jointly by the cost analysis groups of NASA/MSC and the Grumman-Boeing Team. This section also includes a definition of concept development schedules, operations traffic models and the related operational fleet size.

2.1 Costing Guidelines

Industry experience with prior aircraft, spacecraft, and missile programs has been used extensively in projecting Shuttle program costs. In developing the costing analysis, however, it was recognized that the Shuttle concept, which combines elements of both aircraft and spacecraft, is without precedent on an operational basis. In addition, the basic program goals specifically established for the Shuttle program significantly affect costs. To provide for these considerations, a number of basic guidelines were formulated for the costing analysis, thereby permitting credible extrapolation of previous experience to Shuttle system application. The guidelines which have been used to derive current costs are summarized in the following paragraphs.

2.1.1 Program Costs

The guidelines listed below were applied to the program, in general, to arrive at current cost figures. As general guidelines, they influenced the costs projected for all cost elements and all concepts.

a. First Manned Orbital Flight (FMOF) occurs in late 1977.

b. The baseline operational program extends for 10 years from FMOF.

c. Four traffic models were used, comprising the NASA standard (total of 445 flights) plus three alternatives (totals of 100, 220, and 365 flights).

d. Costs were presented in CY 1970 dollars.

e. KSC was baselined as the primary launch site.

f. Reported costs did not include contractor fees and NASA management costs.

g. Cost projections were based on the total program cost structure shown in Table 2.1-1(a).

h. Ten percent General and Administrative (G&A) costs were applied to the airframe, internal tankage, TPS, and subsystem integration for all orbiters and the C-4 booster. The S-1C was costed at its established rate which includes G&A costs. All other program elements were considered to be direct government purchases which included appropriate G&A costs.

i. System Integration and Management costs were applied at the rate of 10% for DDT&E and 5% for Production and Operations.

j. Discounted costs, where cited, were based on rates of 10% and 5% applied to CY 1970 dollars.

2.1.2 Vehicle Subsystems Development and Production

In addition to those guidelines which apply to all cost elements, the following guidelines were applied for projection of vehicle and subsystem development and production costs.

a. Subsystems were costed in accordance with the Flight Articles (Orbiter/Booster) cost structure shown in Table 2.1-1(b).

b. NASA Shuttle cost data was used for all Avionics, EPS, and EC/LSS cost estimating. Since the NASA cost data was derived from a 2 stage fully reusable shuttle, this data was modified, as necessary, to reflect system design differences among concepts.

c. Basic vehicle costs were derived from the Planning Research Corporation R-547A program for aircraft, suitably modified to reflect shuttle requirements.

d. Common development of main rocket engines for both the Orbiter and Booster was charged to the Orbiter.

e. Expendable rocket hardware was procured in the year in which it was used during the operational phase.

(a) Total Program	(b) Flight Articles (ORB/BSTR)
Total DDT&E	
Vehicle (ORB/BSTR)	Structure
Structure	Main Tanks
Main Tanks	TPS
TPS	Main Prop.
Main Prop.	Air Breathers
Air Breathers	OMS
OMS	APS/TVC
APS/TVC	Avionics
Avionics	Power
Power	ECLSS
ECLSS	Interstage
Interstage	
Grnd Test Hdwr	Main Engine
Flt Test Veh	
Grnd Test Ops & Supt	
Grnd Test Fac	
Mfg Fac	
Veh Supt Equip	
Main Engine	
Flt/Com Test Ops & Supt	
Flt/Com Test Fac/GSE	
Sys Int/Mgt	
Production Total	
Flight Articles (ORB/BSTR)	
Test Veh Conver	
Prod Fac (Addl)	
Sys Int/Mgt	
Operations Total	
Ops & Support	
Materials	
Ops Fac/GSE (Addl)	
Sys Int/Mgt	

Table 2.1-1. Cost Structure

f. Recoverable production vehicles were procured at a rate to minimize peak funding.

g. Learning curves were applied to whole vehicles rather than to individual subsystems. While no learning was applied for reusable vehicles, a 95% learning curve slope was assumed for SRM production and 90% for expendable tank production.

2.1.3 Vehicle Test and Operations

In addition to the general guidelines listed in paragraph 2.1.1, additional guidelines affecting test and operations costs were imposed. Those guidelines which were generally applicable to all configurations are summarized below.

a. Quoted costs reflected only contractor effort. Normally government supplied support, such as mission control and range safety, were not included.

b. Vehicle final assembly and checkout were performed at the prime site.

c. KSC was baselined as the prime launch site.

d. Launches were assumed to occur at equal intervals.

e. Orbiter missions were assumed to be of constant 7-day duration.

f. Two shift operations were assumed during phases with launch rates greater than 25 per year.

g. Seventy-five percent of all reusable vehicle test and checkout was assumed to be accomplished by on-board checkout capability.

h. Operations manpower requirements were based on:

- All Time-Line and Manpower Loadings to Derive Manhours Based on 100th Unit Flow. Backup a 90% Learning Curve to Derive First and Subsequent Units. Assume No Learning After 100th Unit.

- Time Lines & Functional Flows for Each Configuration Developed to Level of Recovery; Rec'g & Inspect; Maint. & C/O; Erection & Mating; Transfer to Pad; Pad Pre-Flight Operations
- Manloading (No. Of Heads) Developed to Functional Task Level (e.g., Propulsion Sys. Maint. & C/O; Gnd. Sys. O&M, Refurbishment, Propellant Loading O&M; Erect & Mate) in Terms of Quantity of Mechs. & Techs. for Direct O&M
- 15% of Total O&M Mechs and Techs Added for Quality Control
- 5% of Total O&M Mechs & Techs Added for Scheduling, Records Keeping, Safety, Planning, & Operations Controllers
- 10% of Above Total Added for Engineering and Supervision to Establish Total Direct Heads Per Crew. This Yields Total "Vehicle Contractors" Manpower
- 200% of Above Total Added for "Base Maintenance & Support" to Derive Total Cost Per Processing. This Category by Definition Includes: Maint. of Grounds & Buildings; Protocol; Guards; Cafeteria; Medical; Photo; Repro.; Computer Services; Base Administration; GSA; Fire; Security; Consummable Delivery; Spares Warehousing; Support Shops & Labs
- Range Support & Tracking is not Included (Not Configuration Selection Delta - Predominately Orbiter Sensitive)

i. Test manpower estimates were based on detailed analysis of major ground and flight test activites.

j. Test activities associated with system, subsystem, component, material, wind tunnel and related design and development were assumed to be included in normal DDT&E costs.

Individual concepts were sufficiently different in configuration to necessitate specific guidelines addressed to each concept. These were:

k. Concept A

- Maximum use of existing KSC LC-39 systems
- Erect and mate on mobile launchers using crawlers for pad transfer
- On-site checkout, erect and mate of solids in new assembly building, north of existing VAB
- When launch rates exceed 25 flt/yr, on-site checkout of strap-on motors accomplished in horizontal position prior to erect and mate.
- All recovered hardware (except solids) refurbished at launch site.
- Strap-on recovery operations use a converted tanker and MSTS services. Flush/purge/preservation operations are performed during return to launch site.

l. Concept B-1

- Maximum use of existing KSC Apollo/Saturn systems.
- Erect and mate on mobile launchers using crawlers for pad transfer.
- When launch rates exceed 25 flt/yr., on-site checkout of booster elements accomplished in horizontal position prior to erect and mate.
- Recovered hardware (B1B) is refurbished at the launch site.
- B1B recovery operations use a converted tanker and MSTS services. Flush/purge/preservation operations are performed during return to launch site.

m. Concept B-2

- Maximum use of existing KSC Apollo/Saturn systems.
- Erect and mate on mobile launchers using crawlers for pad transfer.
- On-site checkout, erect & mate of solids (B2 E, F, I) accomplished in new assembly building, north of existing VAB.
- When launch rates exceed 25 flt./yr. on-site checkout of booster elements accomplished in horizontal position prior to erect and mate.

n. Concept C

- New maintenance, mating, and travelways required
- New launch pads or major modifications to existing LC-39 required
- Horizontal mating
  - Transfer to pad on booster landing gear
  - Supplement booster landing gear with bogie wheels
  - On-pad erection
- Solid rocket motors
  - Segment build-up in remote area
  - Mated on-pad after erection

2.1.4 Program Facilities

The costs for facilities and GSE considered the general guidelines contained in paragraph 2.1.1 as well as the following items which are unique to this cost element.

a. KSC was baselined as the prime launch site.

b. Final assembly and checkout were performed at the prime site.

c. Launch Complex 39 was assumed to be available exclusively for Shuttle use.

d. Existing LC-39 facilities and GSE were used whenever possible.

e. Modification or new facility costs were applied only when demanded by specific configuration requirements or traffic models.

- Mating of SRM's to the shuttle required a new SRM integration building.
- New erecting capabilities were required for Concept C boosters.

f. Multiple work shifts were used to the greatest extent possible before imposing requirements for additional facilities or GSE.

g. Facilities and GSE were planned to effect minimum time on the launch pad.

h. Maximum use of automated test and checkout was assumed.

i. For all concepts, each stage was assumed to undergo checkout to a maximum launch readiness status prior to mating and transfer to the launch pad.

j. For fully reusable stages, 75% of the GSE requirements for test and checkout were assumed to be satisfied by on-board checkout capabilities.

k. All new or modified GSE costs were referenced to existing known GSE costs on the basis of relative complexity factors of an airborne system.

l. Nominal aircraft logistic support facilities, such as meteorological services, at landing sites were not included in cost projections.

m. It was assumed that manufacture of major subassemblies was accomplished at Michoud for liquid propellant vehicles, and in Georgia for solid rocket motors.

2.2 Traffic Models/Development Schedules/Vehicle Allocation

The operations traffic model, concept development schedules and vehicle allocations for development and operations are three of the basic elements necessary for deriving total program costs. This section describes the specific traffic models used for cumulating operations launch and refurbishment costs. In addition, it contains the basic development schedules used for estimating major ground test and flight test development costs. Finally, it describes the vehicle allocation necessary for initial development manufacturing and subsequent operations production.

2.2.1 Traffic Models

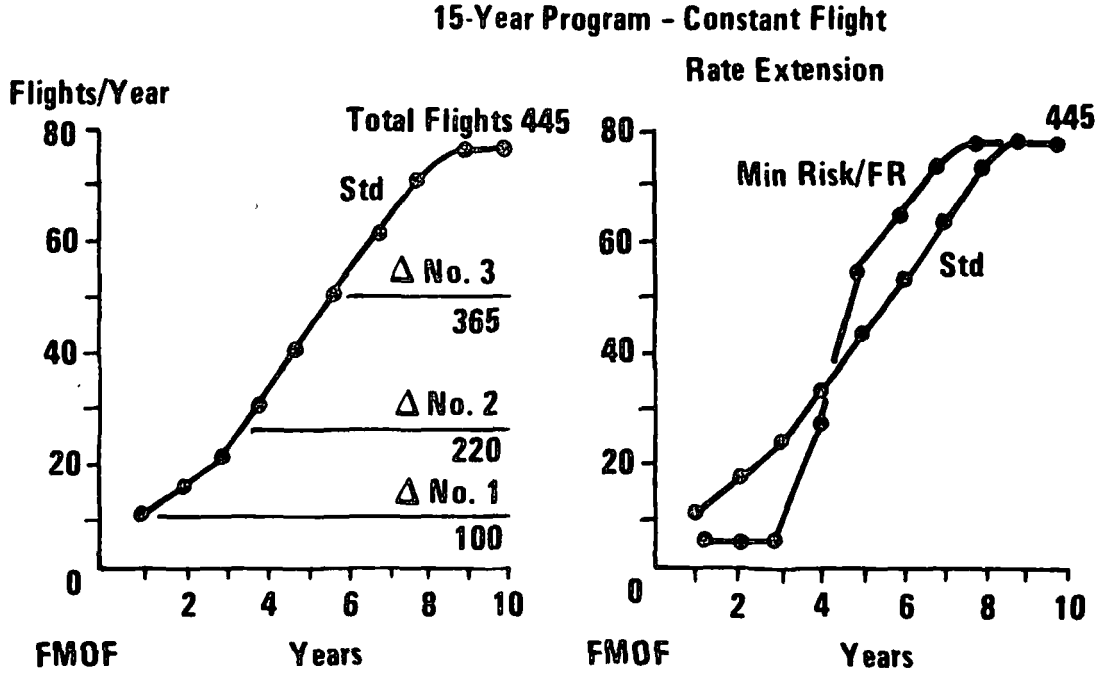
At the initiation of the ASSC study, NASA established a standard traffic model which built-up from 10 to 75 flights per year, accumulating a total of 445 flights for a baseline 10-year operational program. To establish cost sensitivities to launch rate and total program flights, three additional traffic models were defined with peak launch rates of 10, 25, and 50 flights/year. These alternate models result in total program flight accumulations of 100, 220 and 365, respectively. The launch rate profiles of the standard and alternate models are shown in Figure 2.2-1(a).

It is recognized that once the shuttle system becomes operational, its application may extend well beyond the baseline 10-year program life. To determine the implications of longer duration programs, costs were also projected for a 15-year program. For this study, the NASA standard traffic model was extended for an additional five years at the peak traffic rate of 75 flights/year, resulting in a total flight accumulation of 820 flights.

To provide a consistent basis for cost comparisons, the preceding traffic models were applied to all concepts under study with the exception of the $C\text{-}4_{I/II}$ alternative. This approach entails delaying development of a reusable booster for three years and utilizing a modified S-1C as an interim booster. This enables meeting the FMOF schedule and supporting the minimum risk/fully reusable development/demonstration program at the rate of 3 flights/year. The NASA standard traffic model was modified to reflect this low initial flight rate, as shown in Figure 2.2-1(b). The revised model attains coincidence with the NASA standard model in the 9th year with an accumulated total of 370 flights and peak launch rate of 75 per year. Hence, the minimum risk/FR traffic model also culminates in 445 total flights after 10 years of operation.

2.2.2 Development Schedules

Development schedules were formulated for each concept to assist in the pricing of the various shuttle configurations under study. These schedules, initially developed early in the study, have been continually refined as configurations have become better defined and more data has become available from related analyses.



(a) (b)

Figure 2.2-1. Traffic Models

The development schedules, as they currently exist for each concept, are summarized in Figure 2.2-2. Individual schedules to a greater depth are provided in Figures 2.2-3 through -6 for Concepts A, B, C, and the Minimum Risk/Fully Reusable System alternative, respectively.

These schedules have been used to identify requirements and the proper phasing of major cost elements such as ground and flight test articles, and major test facilities and equipment. Refinement of the development schedules during the period between the 6-week and 3-month reviews indicated a reduction of Concept C flight test boosters and orbiters from 3 to 2 each. This decrease is reflected in the Concept C schedule shown in Figure 2.2-5. For costing purposes, however, the Concept C program was costed with 3 flight test orbiters since a similar reduction could not be realized for Concepts A and B.

Additional refinement of the development schedules is continuing, with particular emphasis on sub-orbital flight test requirements and system/subsystem development.

2.2.3 Vehicle Allocation

Current program costs are based on the vehicle allocations defined in Figure 2.2-7 for each of the concepts under study. These allocations identify the articles required for both the test and operational phases of the program.

The requirements for operational fleet vehicles have been based on the following assumptions:

a. All flight test vehicles will be converted to operational status at the conclusion of their test activities.

b. Operational launches occur at equal intervals.

c. Operational orbiter missions were held constant at 7 days duration each.

d. Vehicle operational lifetime equals 100 missions (except as noted for 15-year program).

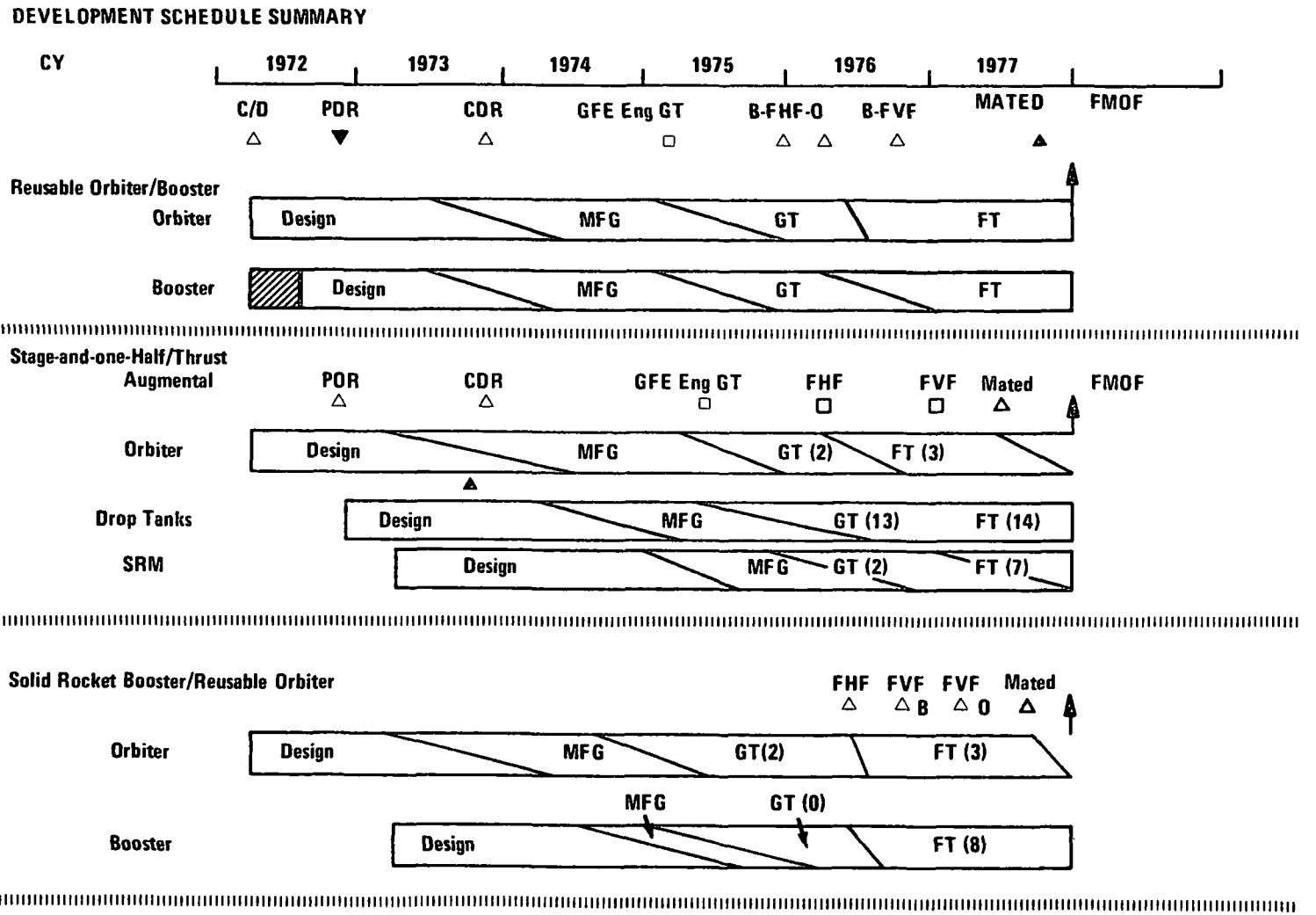


Figure 2.2-2. Development Schedule Summary

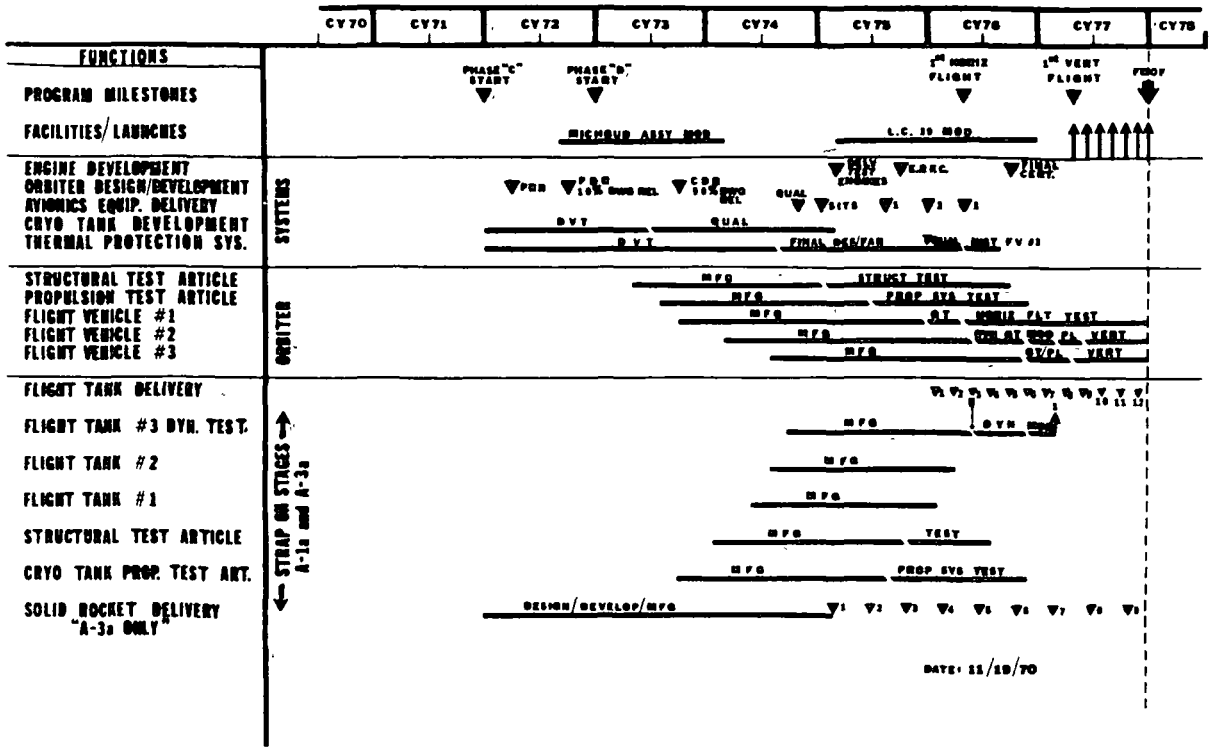


Figure 2.2-3. Concept A - Space Shuttle Program Development Schedule

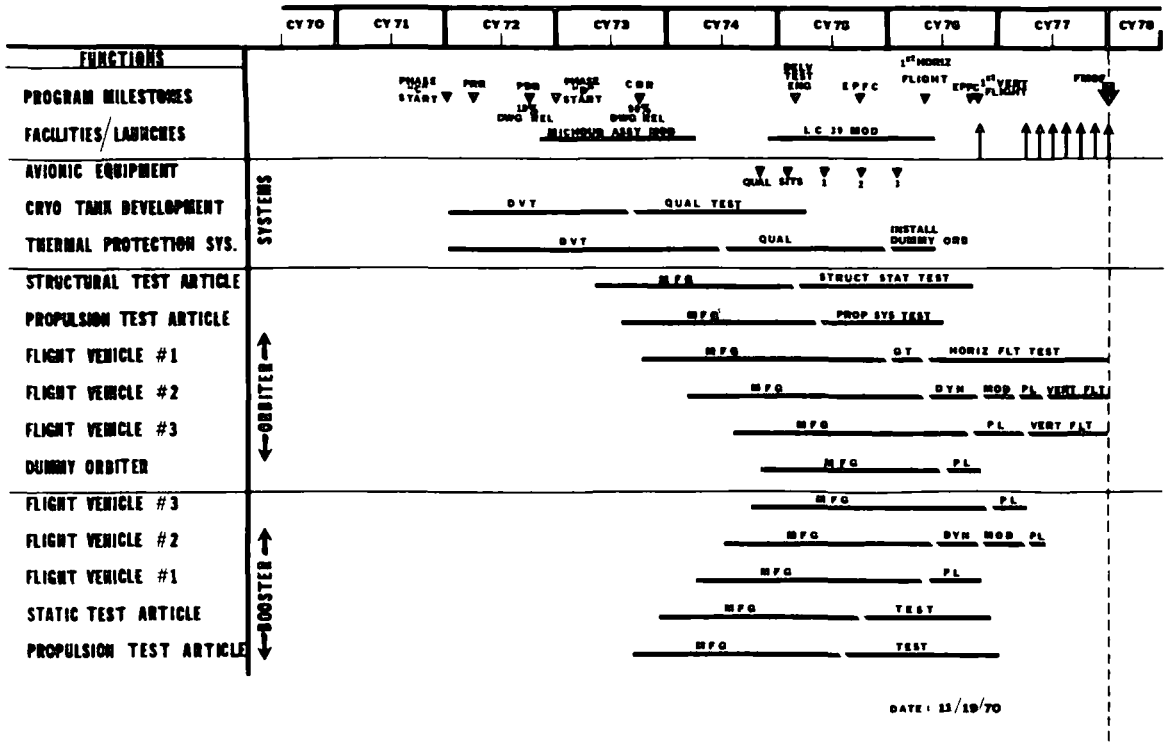


Figure 2.2-4. Concept B - Space Shuttle Program Development Schedule

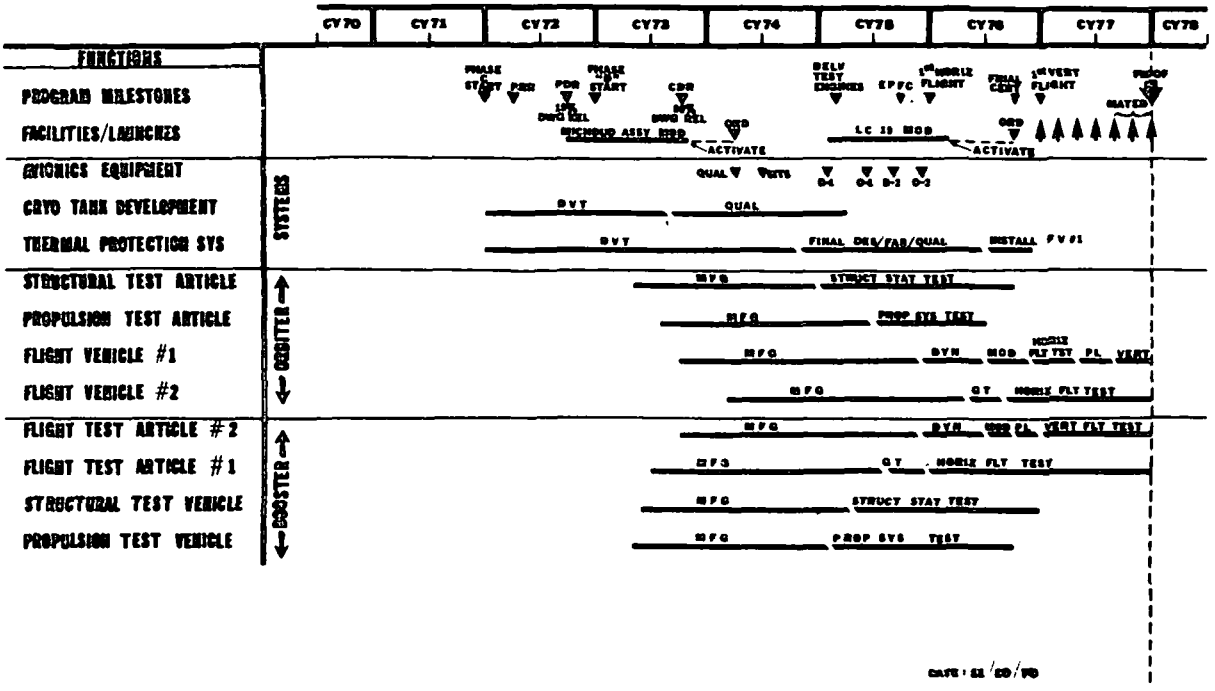


Figure 2.2-5. Concept C - Space Shuttle Program Development Schedule

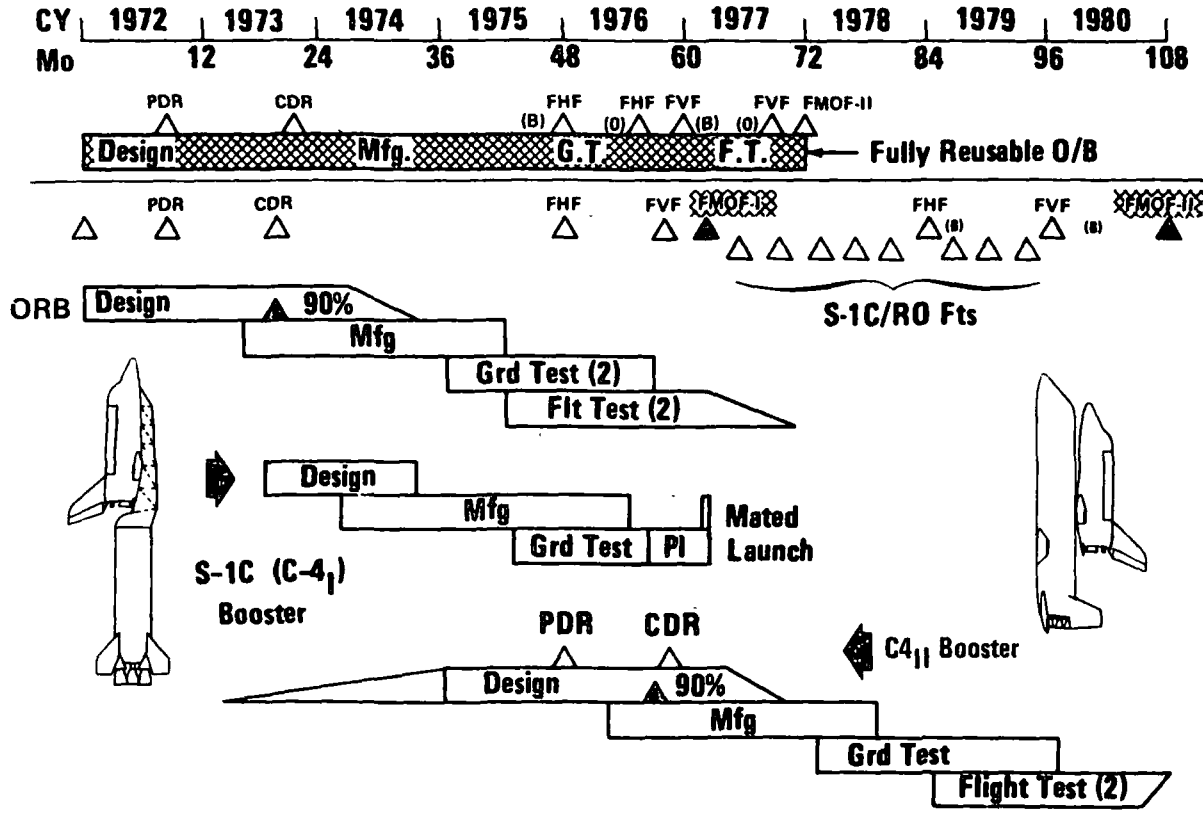


Figure 2.2-6. Minimum Risk Fully Reusable System, Program Schedule

	A-3A		B-1A		B-2		C-4	
	Orb	Tanks/SRM's	Orb	S-1C/STBK	Orb	2d/2i	Orb	Bstr
● Test Operations								
- Structural Art.	0.75	1/0	0.75	0/1	0.75	0.75/0	0.75	0.75
- Propulsion Art.	0.75	2/2	0.75	-	0.75	0.75/0	0.75	0.75
- Bstr - Dummy Orb	-	-	-	-	0.2	-	-	-
- Flt Test Veh/ Modal Survey	3	14/7	3	7/7	3	8/8	3	2
● Operational Fleet								
- Flt Test Veh Conversion		-		-		-		
- Total Fleet 100 Flt	3	200/100	3	100/100	3	100	3	3
- Total Fleet 220 Flt	3	440/220			3	220	3	3
- Total Fleet 365 Flt	4	730/365			4	365	4	4
- Total Fleet 445 Flt-10 yr	5	890/445			5	445	5	5
- Total Fleet 820 Flt-15 yr	9/6*	1640/820			9/6*	820	9/6*	9/6*

*No Vehicle Life Limit

Figure 2.2-7. Vehicle Allocation

The net result of these assumptions is that for the low rate traffic models (i.e., 100 and 220 total flights), the orbiters used in the flight test program for each concept will completely satisfy the operational fleet requirements. The higher traffic rate models (365 and 445 total flights) and the 15-year program (820 total flights) all require the purchase of additional operational vehicles. If the vehicle operational lifetime limit is relaxed for the 15-year program, however, the total number of required reusable vehicles (boosters and orbiters) may be reduced from 9 to 6. The sixth set of vehicles is maintained for contingency purposes due to the extended length of the program. Expendable elements, of course, are directly related to the number of flights.

Consideration of random launch intervals and assignment of a specific set of vehicles to provide rescue capability may also increase operational fleet requirements. However, these factors are beyond the scope of the current study.

Section 3

PROGRAM COST DESCRIPTION

Section 3 contains descriptions of the methods used in computing and compiling program costs. Beginning with the work breakdown structure to separate the programs into manageable quantities, Section 3 goes on through cost model structure and estimating techniques, and concludes with the derivation of cost objectives for each program.

3.1 Cost Element Matrix

This section presents the Cost Element Matrix (CEM) that was used to coordinate the Grumman/Boeing Cost Data contained in Section 4 of this report. This matrix was prepared to be consistent with both level 3 of the NASA Work Breakdown Structure (Ref NASA Memo JB23, August 1970) and the Grumman/Boeing WBS that will be utilized during Phase C/D. A copy of the preliminary Grumman Boeing WBS is enclosed for reference purposes as Figure 3.1-1. The cost element matrix lists lower level items which comprise the level 3 totals.

Cost data is presented in the contractually required formats in Section 4. These formats are organized as follows:

	Form "A" WBS Item Cost	Form "D", WBS Fiscal Year Cost	Cost Element Matrix
DDT&E - Non-Recurring	Fig. 3.1-2	Fig. 3.1-3	Fig. 3.1-4
Production - Recurring	Fig. 3.1-5	Fig. 3.1-6	Fig. 3.1-7
Operations - Recurring	Fig. 3.1-8	Fig. 3.1-9	Fig. 3.1-10

A brief narrative description of each Level 3 item is given below:

Orbiter System - The costs associated with the complete airframe and installed equipment (minus the main engine which is GFE). It includes all effort associated with the design, development, and production of the complete units (prototype and operational) which satisfy the requirements of their applicable specification. Also includes orbiter and flight test integration effort, ground and flight crew training, training equipment, ground

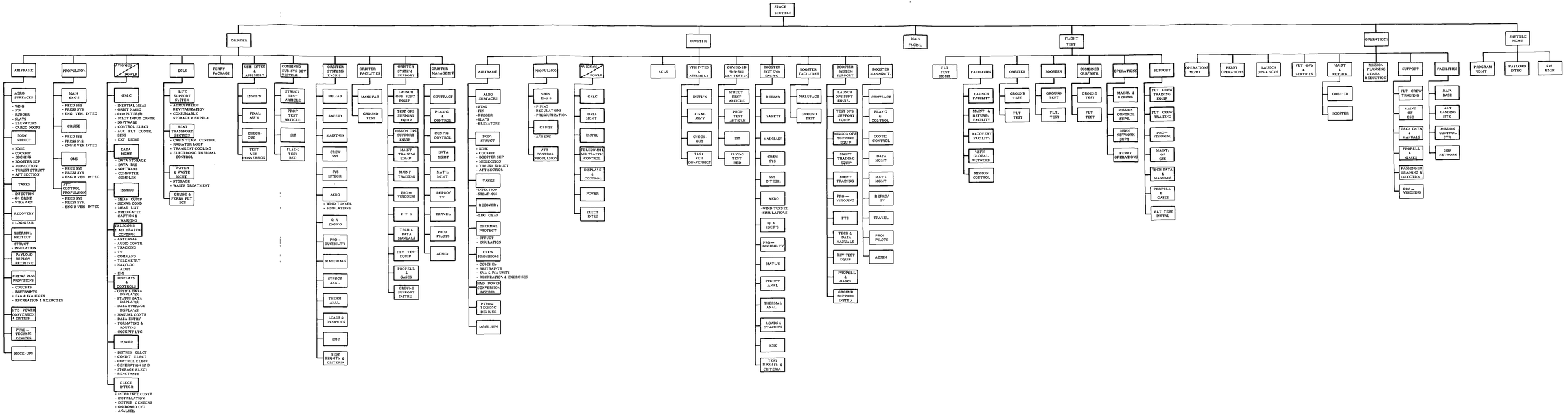


Figure 3.1-1. Work Breakdown Structure

support equipment, ground test and equipment, and propellants and gases. Initial spares, GSE and training for the operational phase are also included.

Booster System - Same as orbiter.

Main Engine - The costs associated with the design, development and production of the main propulsion engine developed under a separate contract and supplied to the Orbiter/Booster contractor(s) as GFE. Does not include tankage or pressurization system.

Flight Test - The costs associated with the use of prototype, production or specifically fabricated hardware to obtain or validate engineering data on the performance of the shuttle system to qualify it for operational use. This includes the detailed planning, conduct, support, data reduction and reports from such operations and production of models, fixtures and instrumentation of the flight test program, but excludes prototype and production units. Includes necessary GSE, special test equipment and propellants and gases.

Operations - The costs associated with all the effort and materials necessary to operate the total shuttle system and maintain it in an operable condition after initial operational capability (IOC) has been established. (The total shuttle system encompasses all Booster and Orbiter vehicles, ground support equipment (GSE) facilities, personnel and operating data.) Specifically, this element includes maintenance and refurbishment of the Booster and Orbiter vehicles after each flight in preparation for the next mission, and maintenance and refurbishment of all GSE and facilities necessary to launch, recover and maintain the vehicles. It also includes all launch operations and services from Booster and Orbiter mating through vehicle installation on the launch pad to liftoff. All flight operations and services from liftoff through the complete Orbiter mission to Booster and Orbiter touchdown and rollout plus ferry operations from alternate landing sites to the primary launch site are also part of this element. This element is limited to manpower, services and consumables (includes propellants and gases but excludes initial operational spares and repair parts).

Program Integration - The costs associated with the technical and business management of the total shuttle program including the planning, directing and controlling the definition, development, and production of the programs; and assuring that planning is accomplished by the organizations responsible for the complementary functions of logistics and maintenance support, personnel training, flight testing, and operational mission mode. Effort which can be specifically associated with the Booster, Orbiter or the engine is excluded.

A comparison of the Cost Element Matrix for DDT&E versus the CEM for Production reveals parallel elements of Orbiter and Booster hardware, facilities, test and support items. The last two elements under the DDT&E Orbiter and Booster are "Ground Test Hardware" and "Flight Test Hardware." In the Production breakdown, a single item, "Test Hardware Conversion", covers the modification of Flight Test Vehicles and Support hardware to the production configuration. The last item is "Production Vehicles" which are, in essence, the total costs associated with all of the above listed elements, including sustaining engineering, manufacturing, materials, and procurement.

It is important to note also that "Program Management" is a Level 3 element of DDT&E, Production and Operations, while "Flight Test" is completed with the Production phase.

"Facilities" appear separately for Orbiter, Booster and Flight Test in both DDT&E and Production phases with procurement of initial facilities, but as a single item in the Operations phase when peak facilities expenditures are past.

3.2 Shuttle Parametric and Cost Estimating Models

Section 3.2 contains descriptions of the parametric and cost estimating models used in analyzing the various Shuttle concepts examined. The parametric model took basic mission characteristics and developed descriptions of Orbiters and Boosters capable of fulfilling those missions. Outputs from the parametric model were fed directly to the cost estimating model wherein costs for these Orbiters and Boosters were developed. Cost was computed for DDT&E, production, and operations. Cost model outputs were in the form of: single costs for non-recurring, production unit, and operations; annual program spreads; and discounted annual spreads.

Date _____

_X_ Non-Recurring (DDT&E) Page _____ of _____

_____ Recurring (Production)

_____ Recurring (Operations)

VEHICLE CONFIGURATION _____ NO. OF FLT _____

WBS IDENTIFICATION NO.	WBS ITEM NAME	WBS ITEM COST	NUMBER OF UNITS
	Orbiter		
	Booster		
	Main Engine		
	Flight Test		
	Program Management		

Figure 3.1-2. Cost Estimate Data Form A

Date _____

__X__ Non-Recurring (DDT&E) Page _____ of _____

_____ Recurring (Production

_____ Recurring (Operations) NO. OF FLT _____

VEHICLE CONFIGURATION _____

PROJECT WBS ITEMS	FY___	FY___	FY___	FY___	FY___	FY___	FY___
Orbiter							
Booster							
Main Engine							
Flight Test							
Program Management							

Figure 3.1-3. Cost Estimate Data Form D

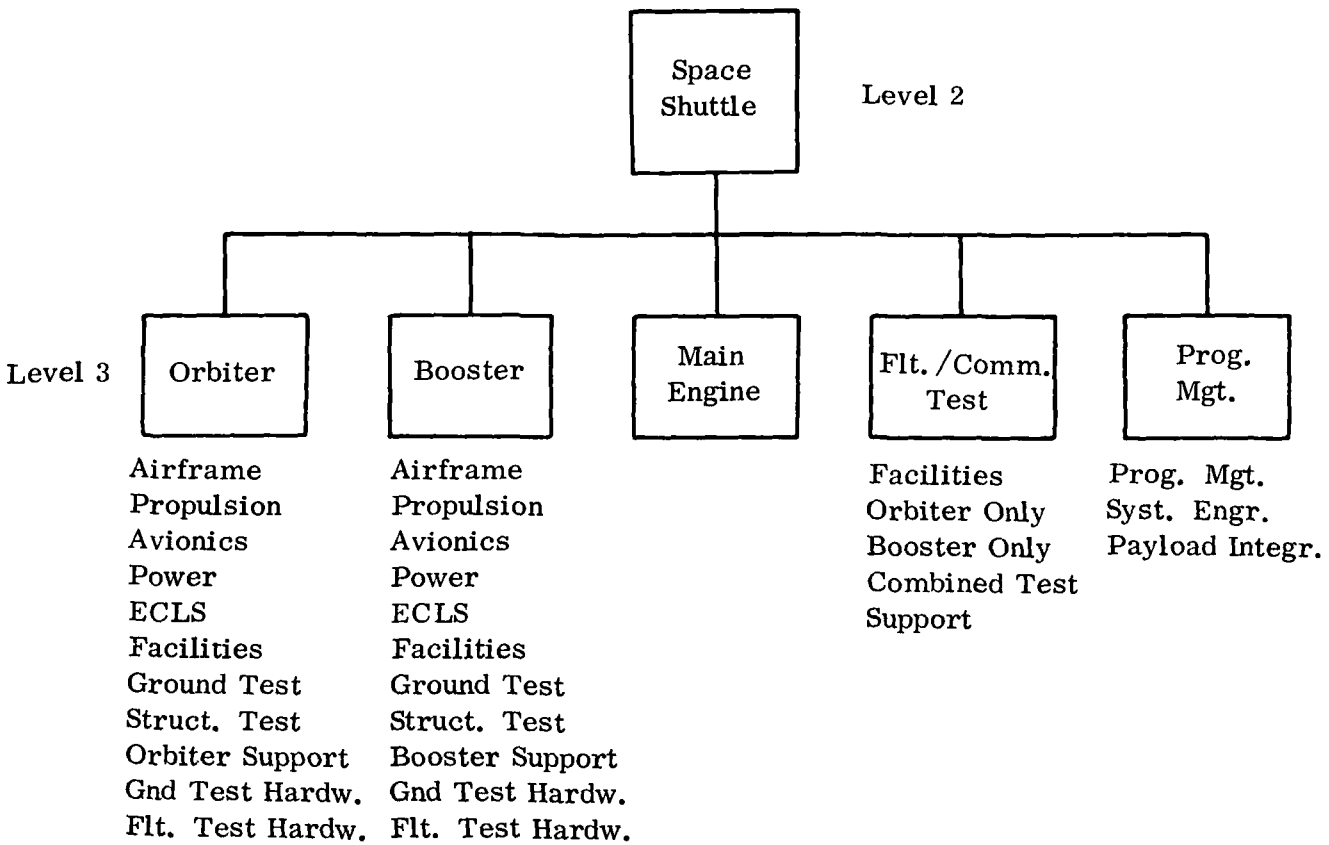


Figure 3.1-4. Cost Element Matrix, DDT&E

Date _____

_____ Non-Recurring (DDT&E) Page _____ of _____

__X__ Recurring (Production)

_____ Recurring (Operations)

VEHICLE CONFIGURATION _____ NO. OF FLT _____

WBS IDENTIFICATION NO.	WBS ITEM NAME	WBS ITEM COST	NUMBER OF UNITS
	Orbiter		
	Booster		
	Main Engine		
	Flight Test		
	Program Management		

Figure 3.1-5. Cost Estimate Data Form A

Date _____

___ Non-Recurring (DDT&E) Page _____ of _____

_X_ Recurring (Production)

___ Recurring (Operations)

VEHICLE CONFIGURATION _____ NO. OF FLT _____

PROJECT WBS ITEMS	FY___	FY___	FY___	FY___	FY___	FY___	FY___
Orbiter							
Booster							
Main Engine							
Flight Test							
Program Management							

Figure 3.1-6. Cost Estimate Data Form D

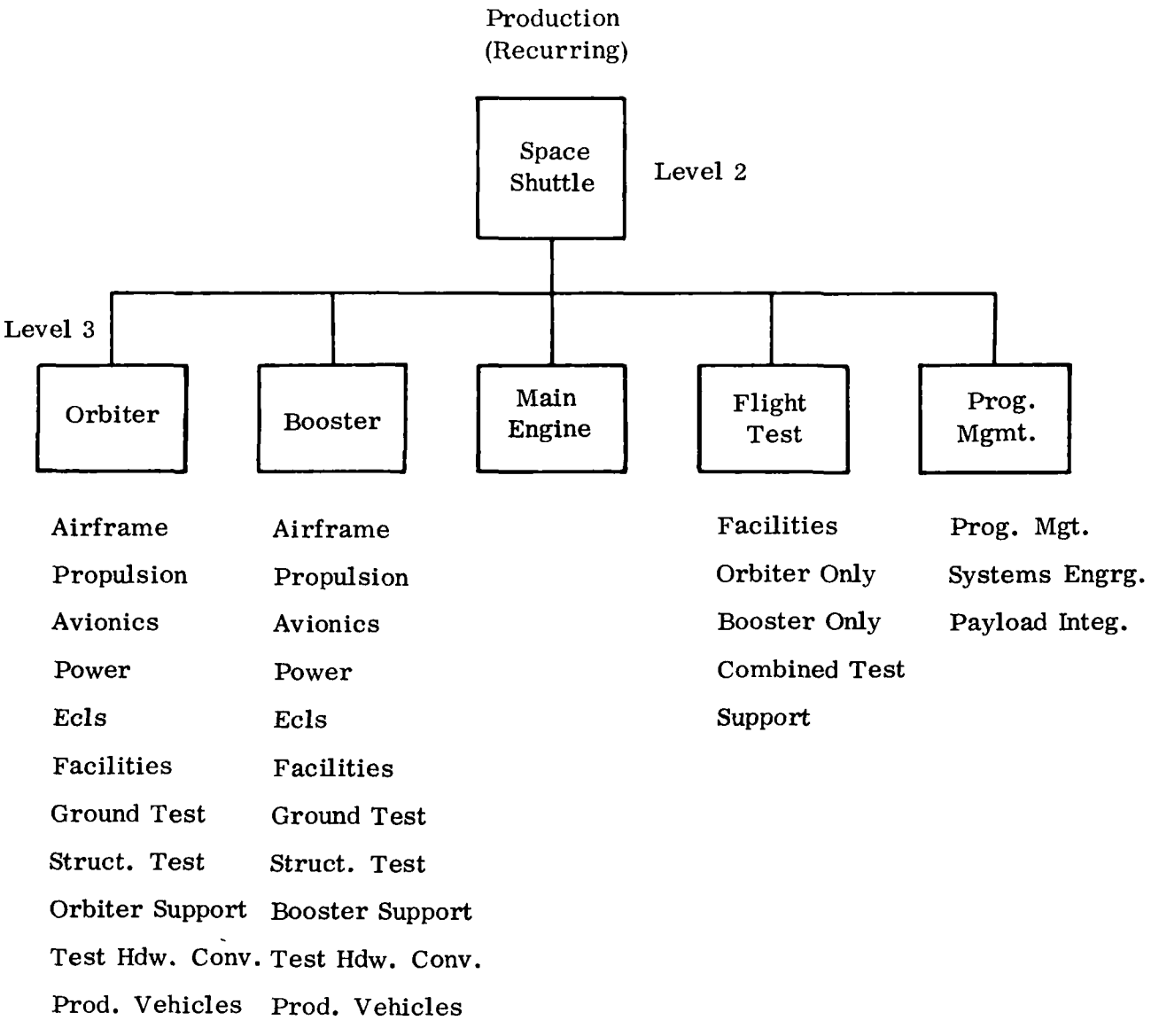


Figure 3.1-7. Cost Element Matrix, Production

Date _____

_____ Non-Recurring (DDT&E)

_____ Recurring (Production)

__X__ Recurring (Operations)

Page _____ of _____

VEHICLE CONFIGURATION_____

NO. OF FLT _____

WBS IDENTIFICATION NO.	WBS ITEM NAME	WBS ITEM COST	NUMBER OF UNITS
	Operations Program Management		

Figure 3.1-8. Cost Estimate Data Form A

Date _____

____ Non-Recurring (DDT&E)

____ Recurring (Production)

__X__ Recurring (Operations)

Page _____ of _____

VEHICLE CONFIGURATION_____

NO. OF FLT _____

PROJECT WBS ITEMS	FY____	FY____	FY____	FY____	FY____	FY____	FY____
Operations Program Management							

Figure 3.1-9. Cost Estimate Data Form D

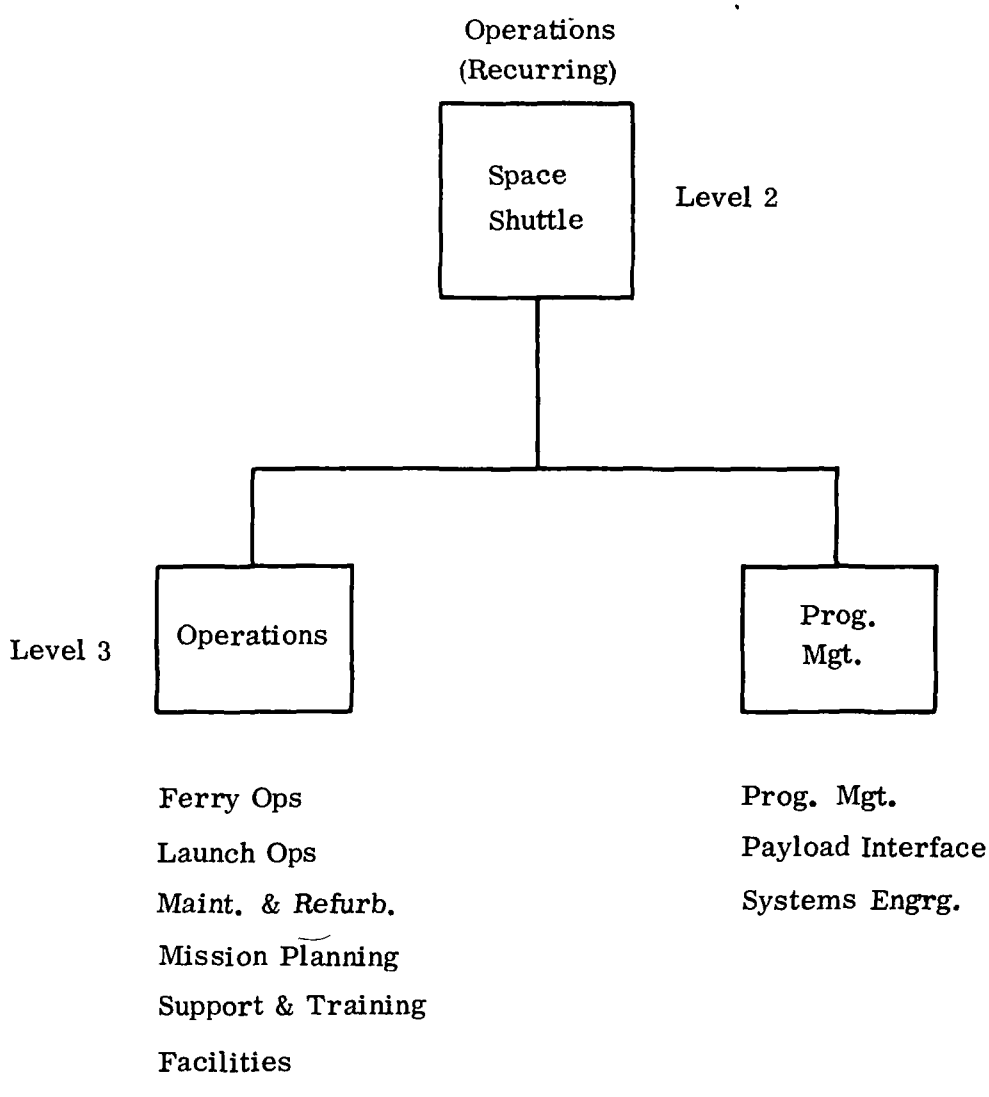


Figure 3.1-10. Cost Element Matrix, Operations (Recurring)

3.2.1 Parametric Model

3.2.1.1 Summary of Model

The Grumman EOS Vehicle Trending Program was specifically developed as a concept screening tool for use during the current Shuttle Study. Over the past year, it has been constantly updated and improved to reflect the latest Shuttle design thinking. Utilizing point design input data, the program provides design direction as well as the necessary inputs to the parametric cost model.

During the initial phase of a parametric design study, it is usually necessary to evaluate many different types of vehicles. These differences may be in the basic design (reusability, number of stages, or aerodynamic configuration) or they may be in the vehicles' performance parameters (delta V allocation, thrust-to-weight ratio, or payload). To determine the sensitivity to any of these variations, it is necessary to systematically vary each parameter, thereby evaluating its effect on the overall system. The Vehicle Trending Program, because of its flexibility, is ideally suited to this job. With a point design vehicle as a reference, the trending program perturbs the appropriate variables and, through an iterative procedure, reconstructs a new vehicle, parametrically sized to include the new variable while maintaining all other constraints. The required trending program input consists of weight, geometry, propulsion, and performance data which describe the baseline vehicle.

The program is capable of handling either two-stage reusable vehicles or a core vehicle with a strap-on solids and/or tanks. It should be noted that, for the two-stage reusable vehicle, the input Orbiter and Booster need not represent a matched pair; the program will resize the vehicles until a working system is achieved.

The EOS Vehicle Trending program's capability to resize vehicles is used to examine the effect on both performance and cost of changing a wide variety of design parameters. Its current use involves determining performance/cost sensitivities to changes in payload, thrust-to-weight ratio, total velocity requirement, packing efficiency, wing loading, and propulsion system type. Tradeoffs of this type provide design direction and allow for the rapid determination of an optimum vehicle. When coupled with the cost model, these tradeoffs may be quickly evaluated and their effect

DESIGN DATA Wing Ref. Area					
Wing Expo. Area					
Wing Span					
Wing Thickness					
Tail Area (Vert)					
(Hori)					
Body Wetted Area (Less Base)					
Crew Compartment Volume					
Cargo Compartment Volume					
Tunnel Volume					
Tank Volume (Main Fuel)					
(Main Oxid.)					
(Aux. Fuel)					
(Aux. Oxid)					
Rocket Engine* Volume					
Air Breather* Volume					
Total Body Volume					
Body Planform Area					
Ideal ΔV					
Thrust-to-Weight					
Number of Engines					
Relative Staging Velocity					
*Major engine cross-section X length X number of engines.					
ENGINE DATA I_{sp} (Sea Level)					
(Vacuum)					
(Eff.)					
Thrust (Sea Level)					
(Vacuum)					
(Sea Level Emer.)					
(Vacuum Emer.)					

Figure 3.2-1. Operations Analysis Vehicle Trending Input Form

on the overall program readily determined. A more detailed discussion of the cost model is included in a subsequent section.

Required Inputs

To utilize the vehicle trending program, it is necessary to provide a definition of the point design vehicle's weight, geometry, propulsion, and trajectory characteristics. Since this data is already inherent in the point design, the trending process does not place any additional burden on the design procedure. Completion of the point design input sheet shown in Figure 3.2-1, together with the design weight statement and estimated velocity losses are sufficient to initiate a trending run.

Basic Program Methodology

The EOS Vehicle Trending Program used weight estimating relationships which are normalized to the input point design data. Figure 3.2-2 shows a standard relation and the normalized counterpart used by the program.

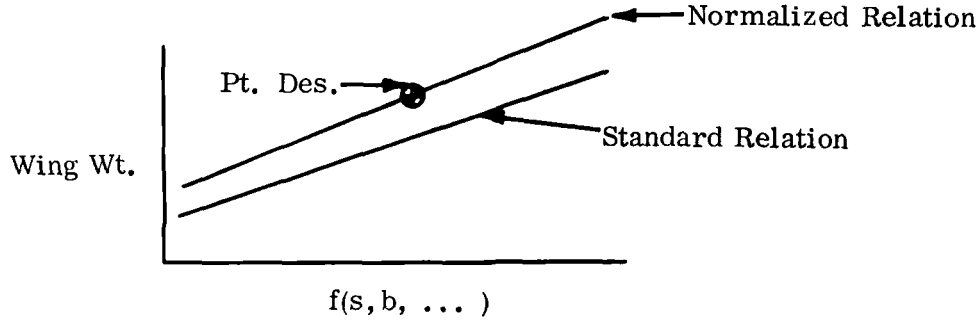


Figure 3.2-2. Standard and Normalized Weight Estimation

Figure 3.2-3 illustrates the basic iterative procedure and the order of calculations within the program. (The flow has been greatly simplified for presentation purposes.)

The total velocity requirement to achieve the reference orbit is assumed to be 24962 feet per second plus orbiter and booster losses. These losses are estimated using statistical relationships. The data base for these relationships was gathered from numerous detailed trajectory calculations performed for representative configurations. Orbiter losses are assumed to be a function of V_{STG} and Orbiter thrust-to weight ratio, and Booster losses are assumed to be a function of V_{stg}, I_{sp}, $C_D A$, thrust-to-weight ratio at liftoff and thrust-to-weight ratio after 120 seconds.

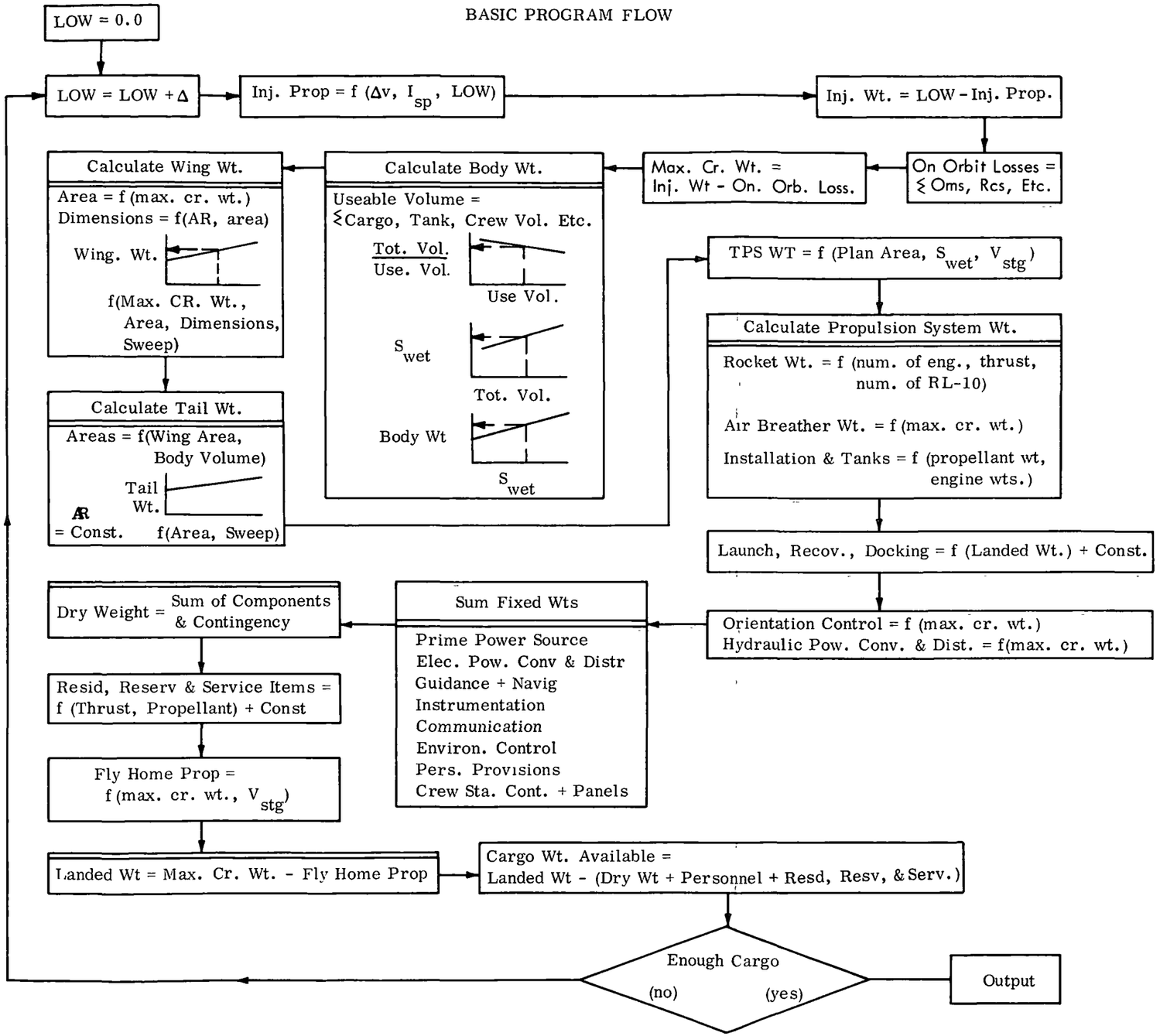


Figure 3.2-3. Basic Program Flow

Output

The EOS Vehicle Trending Program generates several forms of output. Most frequently the output is expressed in the format shown in Figure 3.2-4. The output defines a family of vehicles with constant performance except for variations in ΔV allocation. Since payload capability and thrust (or thrust-to-weight ratio) are inputs to the program, the weight/cost sensitivity to these additional parameters is easily determined. Once an optimum vehicle is selected from the matrix provided by the program, more detailed information may be generated. The form of this detailed output is shown in Figure 3.2-5. As previously stated, the EOS Vehicle Trending Program is also used as a source of input data to the Grumman Shuttle Cost Model. This output is either automatically punched in IBM data cards, or maintained in disk storage until it is needed. The format of the output, used by the cost model, is illustrated in Figure 3.2-6. Much of the data developed by the program is not normally printed as output. Since the program is run on Grumman's time-sharing system, however, the form of the output may be modified for a specific task in a matter of minutes.

3.2.2 Cost Model

3.2.2.1 Introduction

The EOS includes both aircraft and spacecraft characteristics. As a result, a cost model derived to estimate EOS program cost must include cost estimating relations (CER's) that will estimate subsystem cost according to the type of subsystem, aircraft or spacecraft. State of the art must also be considered. These are accounted for in the basic CER as a function of some of the independent variables which act as proxies for increasing technological requirements associated with increasing performance, and modification of equation output to account for concept differences.

The primary CER estimates between 8 and 30% of the total program cost depending on the design concept. It is an airframe cost estimating relationship developed by the Planning Research Corporation (PRCR-547A), for the Systems Analysis Division of the Office of the Secretary of Defense. The output of this model

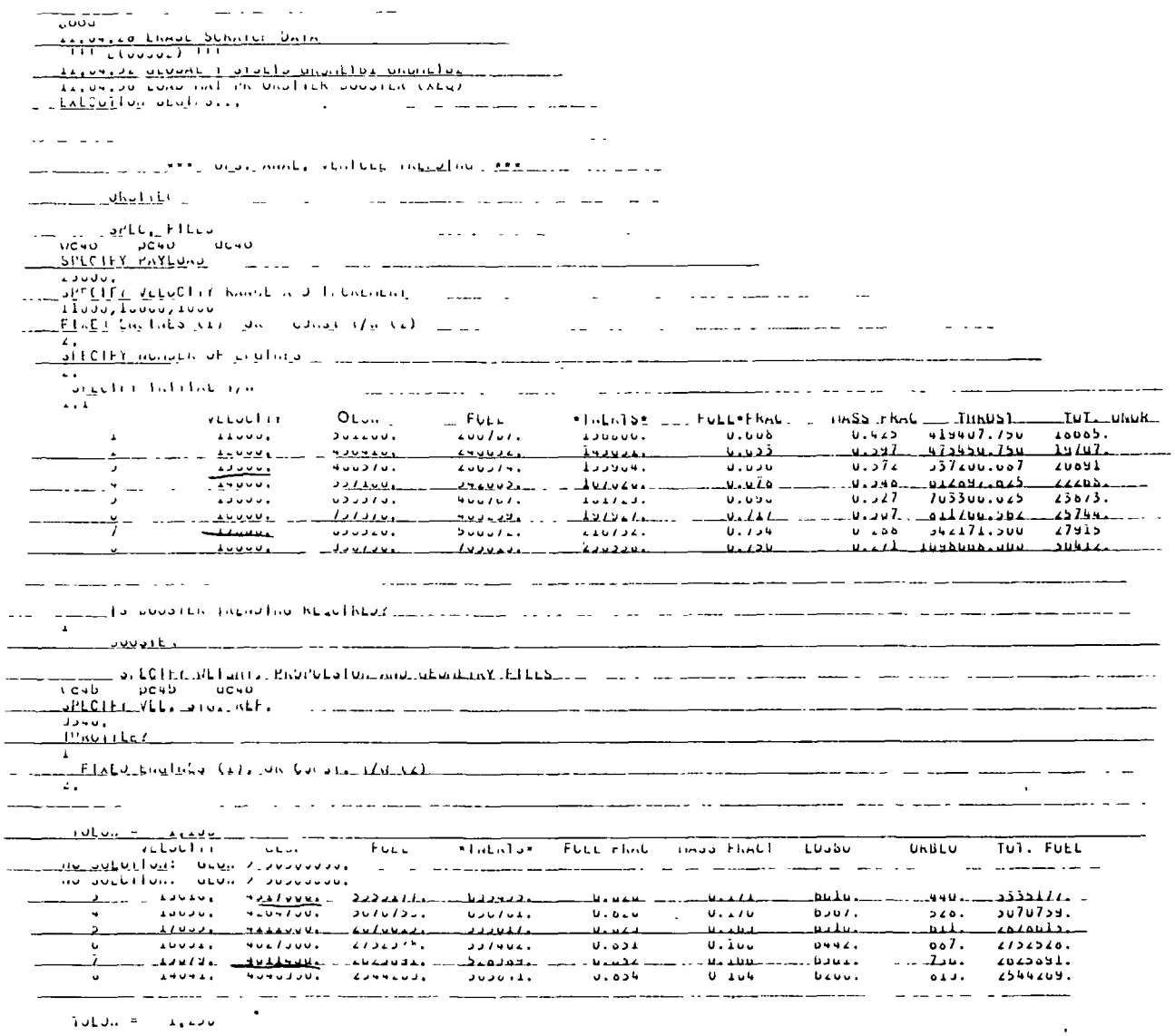
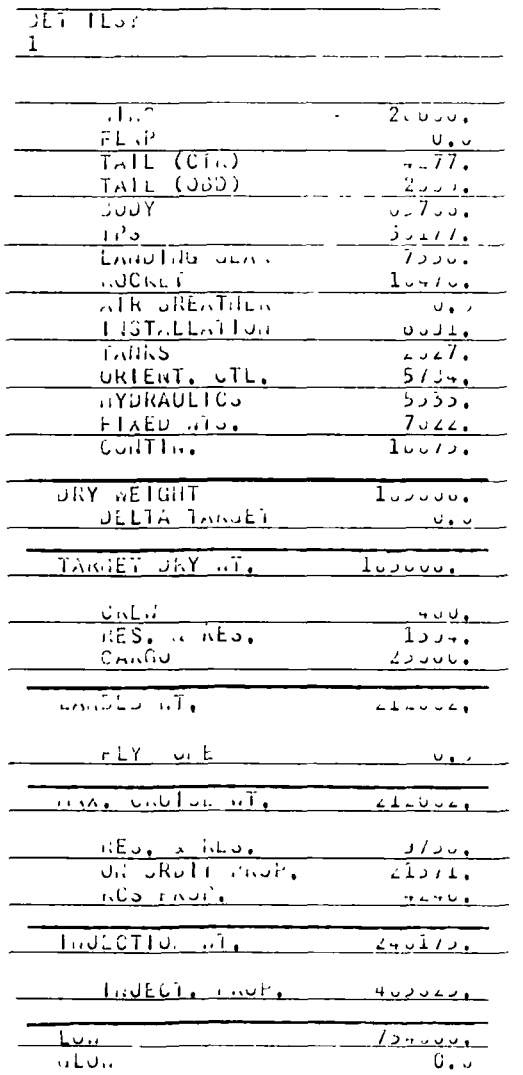


Figure 3.2-4. Vehicle Trending Program Output



JET TLS?	
1	
[illegible]	2[illegible].
FLAP	0.0
TAIL (CTR.)	[illegible]77.
TAIL (OBD)	2[illegible].
BODY	[illegible].
APS	[illegible].
LANDING GEAR	7550.
ROCKET	1[illegible].
AIR BREATHER	0.0
INSTALLATION	[illegible].
TANKS	[illegible].
ORIENT. CTL.	5[illegible].
HYDRAULICS	5[illegible].
FIXED WTS.	7[illegible].
CONTIN.	1[illegible].
DRY WEIGHT	1[illegible].
DELTA TARGET	0.0
TARGET DRY WT.	1[illegible].
CREW	[illegible].
RES. & RES.	1[illegible].
CARGO	2[illegible].
LANDED WT.	[illegible]
FLY BACK	0.0
MAX. GROSS WT.	[illegible]
RES. & RES.	[illegible].
ON ORBIT PROP.	[illegible].
RCS PROP.	[illegible].
INJECTED WT.	[illegible].
INJECT. PROP.	[illegible]
LOX	[illegible].
GLOX	0.0

Figure 3.2-5. C-4 Orbiter Point Design

T/W STAGING	TOGW CORE	TOGW COMBINED	DELTA V 1st STAGE	AMPR	DRY WT.	RCS WT.	TPS AREA

STRUCTURAL DENSITY	FRAME WT. EMPTY	TOGW MINUS SPACE SYSTEMS	FUEL WT. OF CORE	THRUST PER ENGINE	NO. OF ENGINES	TANK INSULATION AREA	INJECTION WT.

Figure 3.2-6. Trending Program Cost Output Format

is modified to provide Shuttle airframe costs for DDT&E and Production. Other CER's are used to estimate TPS, tankage, tank type boosters, rocket motors, avionics and other spacecraft type subsystems. Test, operations, facilities, support and program management are either inputted on the basis of design group estimates or related to other cost categories.

3.2.2.2 Model Development

The cost model development kept pace with the degree of design data available for cost analysis. The initial model, used for the six-week review, included a set of CER's which lacked the sensitivity to concept design, thus precluding cross-concept cost comparisons. As appropriate design data became available, thus allowing modification factors to be derived for affected cost categories, cost estimates for concept alternatives were determined making cost comparisons among concepts possible. Section 3.3 of this volume discusses the cost program modifications.

Costs for the three-month review were derived from the improved EOS cost model. Modifications to the six-week EOS cost model include the following:

- The PRC R-547A aircraft cost estimating relationship modification included:
  1) Establishing titanium cost factors that were more selective with reference to the effect of titanium on airframe cost elements
  2) Establishing cryogenic tank cost factors
  3) Establishing fuel feed system cost as a function of concept anomolies and thrust requirements
  4) Modifying cost estimates to reflect space vehicle subsystems test and checkout requirements
- The DC-3 Avionics cost were modified to reflect concept requirements
- Power Systems were estimated to reflect concept requirements
- OMS added to vehicle cost

- TPS updated to reflect cost of developing components as well as the actual vehicle subsystem. Also, modified production and refurbishment cost to reflect updated cost estimates

Other CER's, notably strap-on boosters and tanks, were updated to reflect added configuration design data.

This current cost model is basically a refined version of the model used for the three-month review, with two exceptions. A new set of SRM cost estimating relationships have been developed by a Grumman/Boeing study group and incorporated into the model. These are discussed in paragraph 3.3.1. Also, insulation costs for the TPS refurbishment costs have been modified to more closely reflect operational conditions.

3.2.2.3 Cost Model Components

Figure 3.2-7 illustrates the cost estimating sequence for generating the required EOS cost analysis data. The primary output of the cost model (dashed lined boxes) include:

- Total program costs for all parametric designs derived from the vehicle trending model
- Annual funding requirements for selected configurations
- Present worth determinations for selected configurations for varying discount rates

Vehicle sizing parameters, required input to the basic cost model to estimate vehicle costs, are provided by the Parametric Vehicle Trending Program. The trending model and a list of required input to the cost model is discussed in paragraph 3.2.1. Other inputs are provided by design groups, Operations Analysis and Test,and the NASA traffic model.

The EOS cost model estimates costs at levels 4 and 5 of the WBS. These are shown in Figure 3.2-8 which lists the cost category by WBS level, input data source and the method used to estimate the cost. It can be seen that contributions to total program costs include those estimated from CER's, NASA inputs and costs derived by "grassroots" means and incorporated as throughputs. A flow chart of the computer program for the EOS Cost Model is given in Figure 3.2-9.

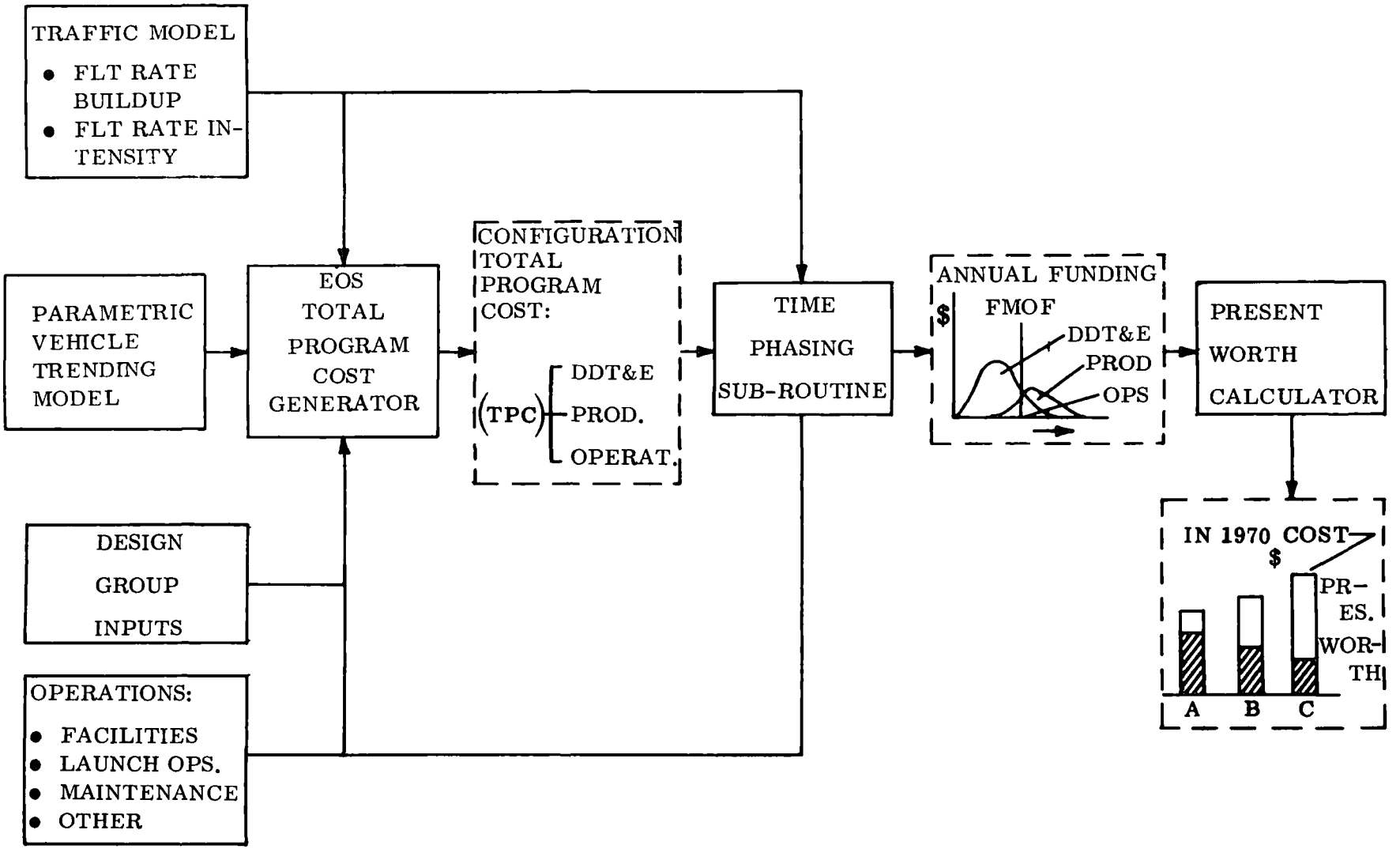


Figure 3.2-7. Cost Estimating Process

L2	Subdivision Of Work	L3	L4	L5	Input & Data Supplied By Source	Estimated By: GAC	TBC	NASA
Space Shuttle	DDT&E	Orbiter	Airframe					
				Main Tanks	Veh. Trending Prgm	PRC R 547A CER Engrg Estimate		
				TPS	Eng Est.			
				Structure	Veh. Trending Prgm			
			Propulsion					
				MPS	Propulsion Grp	MPS Based on Vendor Data & Aerospace Corp. Coefficients CPS-OMS-ACPS, Based on Vendor & In-House Est.		
				CPS				
				OMS				
				ACPS				
			Avionics					
				Avionics	NASA	Modified to Reflect Diff. Configs.		DC-3 Study For 2 Stage Fully Reusable
			Power					
				LC Power Cryo	NASA	Modified to Reflect Diff. Configurations		DC-3 Study For 2 Stage Fully Reusable
				Fuel Cell				
				Batteries				
				APU				LQS DC-3 Study Used as is.
			ECLS					
				ECLS	NASA			
			Facilities					
				Manufacturing	Ops. & Test Area	Operations & Test	Ops. & Test	
				Ground Test	Ops. & Test Area	Area Estimates	Area Est.	
			Ground Test					
					Test Area	Test Area Est.	Test Area Est.	
			Struct. Test					
				Struct. Test	Test Area	Test Area Est.	Test Area Est.	
			Support					
				GSE	Ops. Area	Ops. Area Est.	Ops. Area Est.	
				Test Ops Supt Equip				
				Launch				
				Mission				
				Maint Trng				
				Maint Trng				
				Provisioning				
				Factory Test Equip				
				Tech Manuals				
				Dev. Test Equip.				
				Propellants & Casses				
				G. S. Instrumentation				
			Grnd Test Hdwr		Test Area	Test Area Est.	Test Area Est.	
			Flt Test Hdwr		Test Area	Test Area Est.	Test Area Est.	
		Booster	(Ditto Above)		(Ditto Above	C-4 Only	Except C-4	
		Main Eng			Veh. Trend Prog. Propulsion Grp	Aerospace (Krueger) CER's	P. F. Storage & SRM's	
		Flt./Comm. Test	Facilities					
			Flt./Comm. Test					
			Combined Test					
			Support					
		Prog. Mgmnt.				Estimated at 10% of DDT&E 5% Prod.		
	Production	(Ditto DDT&E Except)			(Ditto DDT&E)			
			Test Hdw Conv. instead of Grd Test Hdw		Test Area	Test Area Est.	Test Area Est.	
			Prod Vehicles Instead of Flt Test Hdw		(Ditto DDT&E)			
	Operations	Operations	Ferry Ops		Ops. Area	Ops. Area Est.	Ops. Area Est.	
			Launch Ops					
			Maint & Refurb					
			Mission Planning					
			Support & Trng					
			Facilities					
		Prog. Mgmt.				Estimated at 5% of Ops. Total		

Figure 3.2-8. EOS Cost Model Characteristics

EOS Cost Model - Total Program Cost Subroutine

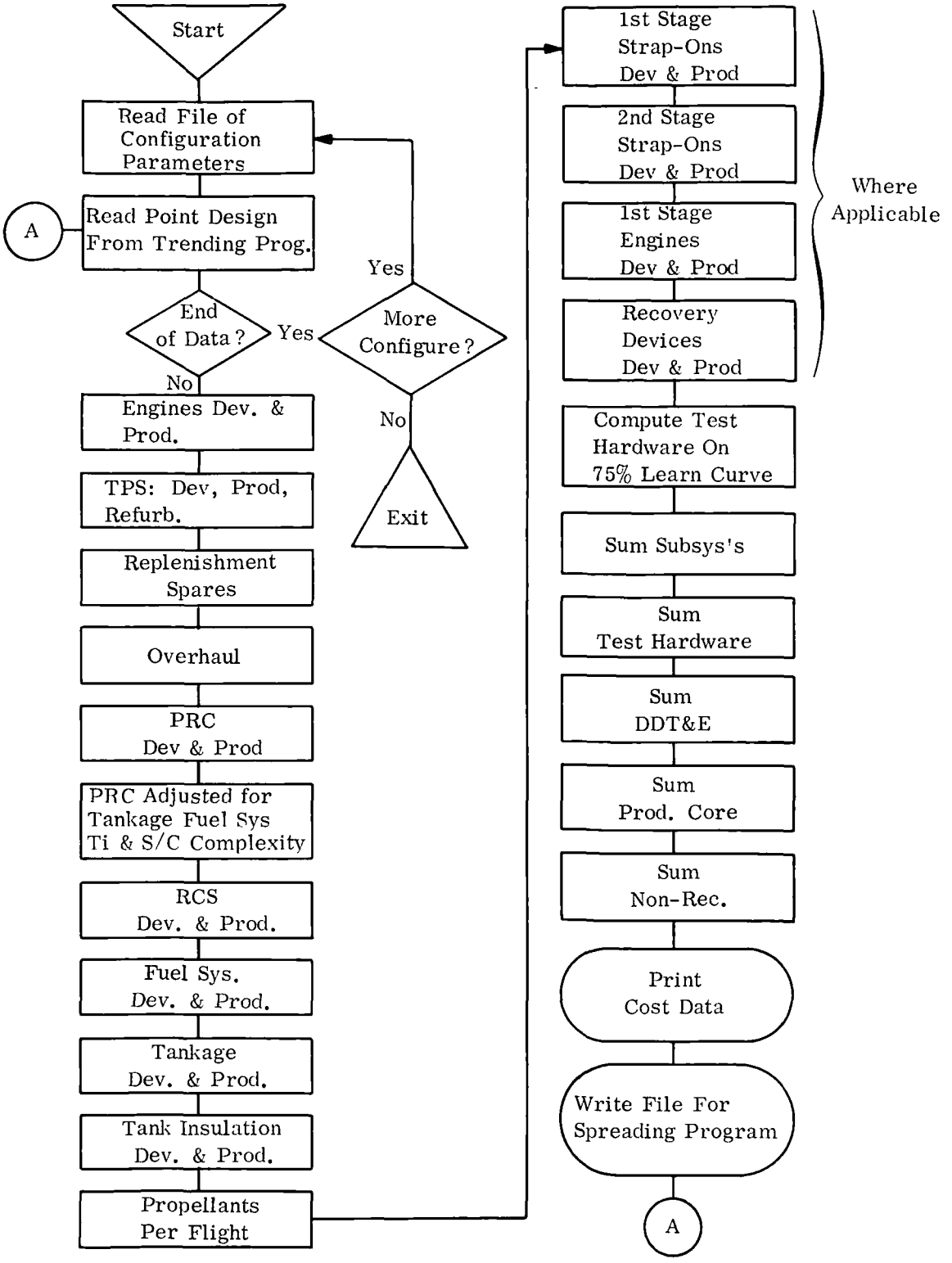


Figure 3.2-9. EOS Cost Model - Total Program Cost Subroutine

Annual funding and Present Worth determinations are calculated according to the procedure outlined in Figure 3.2-10. The time-phasing subroutines perform all of the functions relating to time and schedules. All cost inputs are therefore needed on a per unit basis only.

The major cost items are grouped into the following categories:

- DDT&E
- Non-recurring GSE & Facilities
- Production
- Operating

The cost items in each category are distrubuted over the life cycle of the program. The DDT&E and N/R GSE & Facilities costs are distrubuted over the first seven years, in accordance to specified Beta Function coefficients. The Production and Operating cost items are distributed according to operating flight rates, and for some items according to specified schedules.

Cost totals are computed for each year of the program. With the totals, and with specified discount rates, discounted annual cash flow and the present value of all programs costs are computed.

3.2.3 Cost Distribution

3.2.3.1 Introduction

The nature of the ASSC study, involving DDT&E, Production and Operations requires the application of a number of methods of cost distribution since each phase of the program contains its own peculiar cost elements.

Generally, the DDT&E portion of the program is suited to cost distrubition using the Idealized Cost Distribution Curves of MF 003M, while the OPERATIONS phase is better suited to a cost/flight/year distribution. The PRODUCTION costs assume that any additional facilities will be purchased in a single year, with vehicles purchased over a two year/vehicle period.

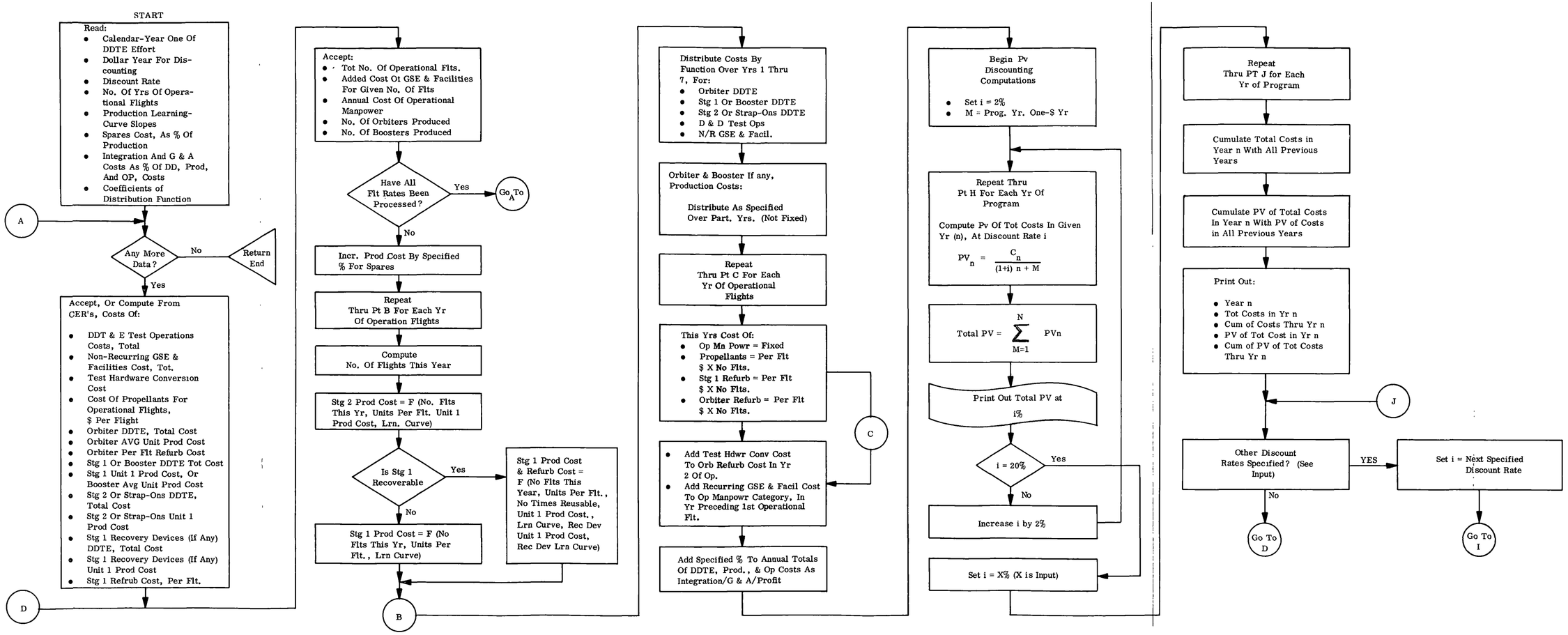


Figure 3.2-10. EOS Cost Model - Time Phasing and Present Worth Subroutines

3.2.3.2 Distribution of DDT&E Costs

The calendar year distribution of DDT&E costs for all configurations follows Beta Function 4 of MF 033M using a seven-year period. The results of this distribution are used wherever annual (calendar) costs or cumulative costs are displayed.

To relate the same cost to a Fiscal Year distribution, a more detailed analysis was performed. Each element of cost at WBS level 3 was distributed to its own Beta Function (see below) over 14 semi-annual periods.

Orbiter	=	Beta Function 3
Booster	=	Beta Function 4
Flight Test		
Hardware	=	Beta Function 4
Testing	=	Beta Function 5
Main Engine	=	Beta Function 3
Mgt/Sys Inte	=	Proration

3.2.3.3 Distribution of PRODUCTION Costs

Production cost distribution followed the simple expedient of assuming that a vehicle unit cost was distributed over two years. Any additional facilities were purchased in the year preceding the start of that production unit required to support the traffic model.

Expendable tanks or SRM's were purchased in the year in which they were required to support the traffic rate.

Conversion to Fiscal Year costs was accomplished by assuming that the expenditure in each half of a calendar year was equal, and by arithmetically accumulating pairs of half-year costs.

3.2.3.4 Distribution of OPERATIONS Costs

The distribution of operations costs considered three elements of cost individually, and spread each on its own basis.

1) Additional Facilities

Additional facility requirements were costed in the first year prior to their use in the operations phase of the program.

2) Management/Systems Integration

Management/Systems Integration costs were spread uniformly over the 10 years of operations as a level of effort function.

3) Operating Costs

The distribution of these costs was based upon the traffic model, each annual cost being the cost/flight multiplied by the traffic rate.

In each case, the Fiscal Year distribution was determined by assuming that the calendar expenditure in each year was uniform across the year, and distributing the costs equally to each fiscal year.

3.3 Cost Estimating Relationships

As mentioned in Section 3.2.2, the cost model kept pace with the degree of availability of design data. This was reflected in refinements to many of the CER's which made feasible the comparison between concepts. The refinements ranged from in-depth review and analysis of in-house and vendor data (e.g., SRM's) to modifications of NASA supplied basic DC-3 costs to accommodate concept system differences.

3.3.1 Solid Rocket Motors

Solid rocket motors were utilized as the primary and secondary boost vehicles on 12 of the 29 configurations selected for screening during the first six-weeks study period. The solid rocket motor configurations covered a range of 500,000 to 4,000,000 pounds of launch weight.

Estimating relationships were required to derive the development and hardware costs for these configurations as part of the screening process. Since the time available to establish a baseline CER was very limited for the first 6-week study period, the Aerospace STS CER shown in Figure 3.3-1 was used.

As a result of the first six-weeks review, three configurations utilizing solid rocket motors as boost vehicles were retained for further study. A primary task during the second six-weeks study period was the refinement of all cost estimates.

To accomplish this task, it was felt necessary to solicit rocket motor suppliers' technical and cost inputs as a further refinement of the SRM CER. Three major rocket motor manufacturers responded to Boeing, providing data packages with technical data

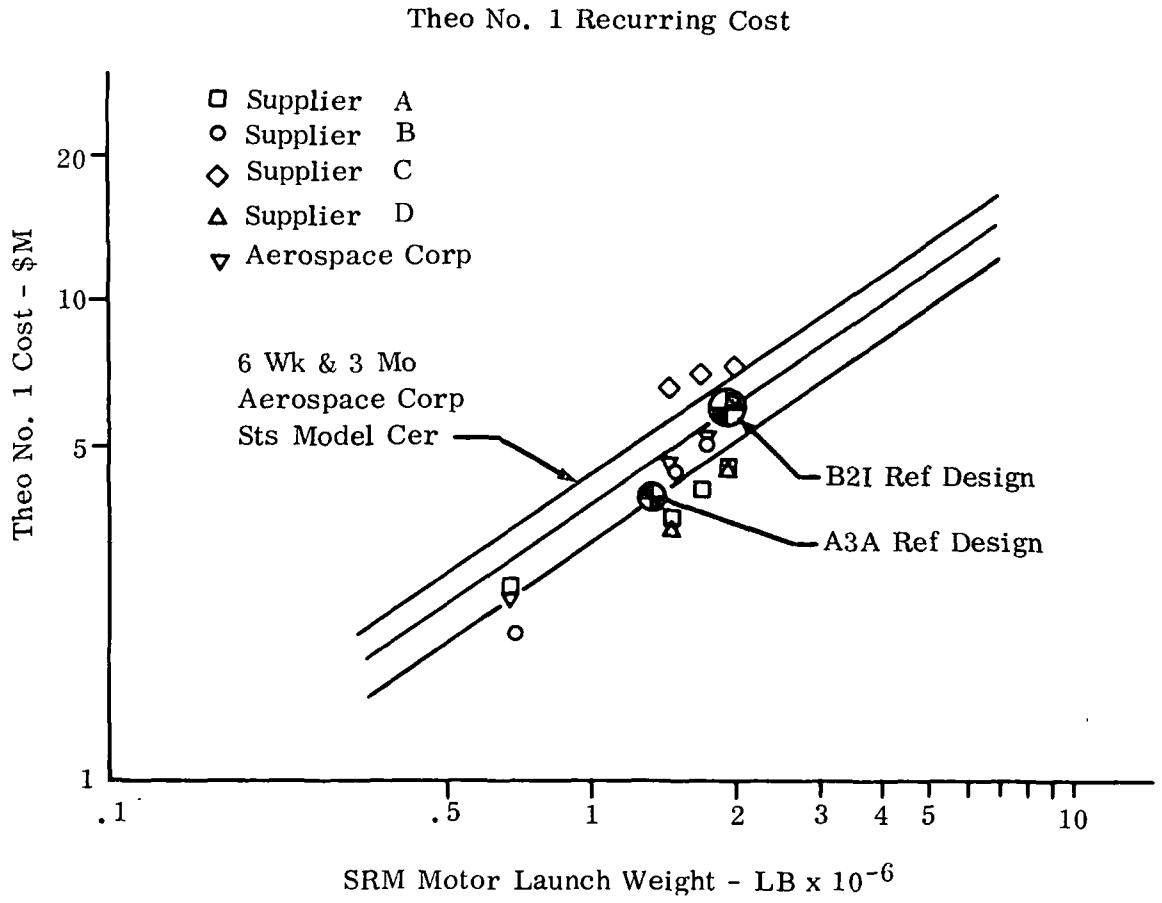


Figure 3.3-1. Mid-Term SRM Cost

and rough order of magnitude (ROM) cost estimates. In addition, the Aerospace Corporation was contacted and provided Titan launch vehicle solid rocket motor costs and SRM cost estimating relationships.

The suppliers' first unit hardware costs were plotted and compared with the first six-weeks CER. Initial supplier data indicated a possible revision to the CER. However, later supplier inputs indicated costs higher than the first six-weeks CER. Based on this data, it was decided to use the first six-weeks CER for the solid rocket cost estimates presented at the three-month review. Figure 3.3-1 presents the supplier data plotted with the first six-weeks CER.

Following the three-month review, a task force was formed to review in-depth the costs for two "B" concept configurations. As a part of this review, the solid rocket motor manufacturers made presentations of their technical and cost data to the task force.

Subsystem cost breakdowns were also presented. The inputs were analyzed and compared to insure an "apples and apples" comparison. A fourth rocket motor manufacturer was solicited for additional technical and cost data. The result was a closer grouping of the SRM manufacturers' cost data. A trend line through the supplier data is currently being used as the SRM CER for the Mid-Term Review for the B2I. This CER is presented in Figure 3.3-1. To represent the A-3A SRM CER, a reduction of 15% was assumed for removal of the thrust vector control. This CER is also shown on Figure 3.3-1.

3.3.2 Pressure Fed Storable Tank Structure

The pressure fed storable tank structure cost estimating relationship includes the total costs necessary to fabricate and assemble all structural items for the B-2d configuration. Both pressurized and unpressurized structural items are included. This CER covers the common bulkhead tanks, thrust structures, intertanks, forward skirt and baffle assemblies. Historical data from the Cost Optimized Launch Vehicle (COLV) Program, the Minimum Cost Design Space Launch Vehicle (MCD/SLV) study contract and various vendor quotations were used in developing these CER's. These studies were based on improved management systems. Current aerospace management systems would result in a total cost increase of 30%. This amount was added to

the COLV historical data to derive the cost estimating relationship for the pressure fed booster structure.

Figure 3.3-2 presents the pressure fed storable structure CER. COLV structure estimates are shown for the first stage and the second and third stages. The experimental stage COLV actual costs are also included on the CER.

3.3.3 Strap-On Tanks

A cost estimating relationship for the "A" concept strap-on tanks was developed utilizing historical launch vehicle, aircraft structure and tankage cost/weight data points. These points were selected to reflect a type of construction similar to the strap-on tank construction.

The majority of the points are actual costs. Several data points are estimates made by major aerospace corporations. A best fit trend line through the data points established the cost estimating relationship (CER). The CER line corresponds closely to the United States Air Force, Space and Missile Systems Office, Los Angeles, Calif. cost estimating relationship for drop tanks. This CER (Figure 3.3-3) was used to calculate the first six-weeks concept "A" cost estimates.

Following the first six-weeks review, studies were conducted to refine the strap-on tank cost estimates. The Boeing Company prepared a series of "grass roots" estimates on three tank point designs. Manufacturing manhours and material dollars were estimated by subsystem for each of the designs. Current labor and overhead rates were applied to these values to develop first unit cost estimates. These estimates provided values slightly less than the existing CER but within the overall CER confidence range. The "grass roots" estimates are plotted on Figure 3.3-3 for comparative purposes.

The "A" concept strap-on tank designs and costs have been compared to similar studies conducted by the General Dynamics Corporation for the Air Force.

The results are presented in Technical Report AFFDL-TR-70-42, dated June 1970. The costs for two configurations are comparable. Propulsion dollar per pound costs compared within 4% and structural costs were within 18%. Insulation costs varied largely because of the manufacturing methods postulated for the

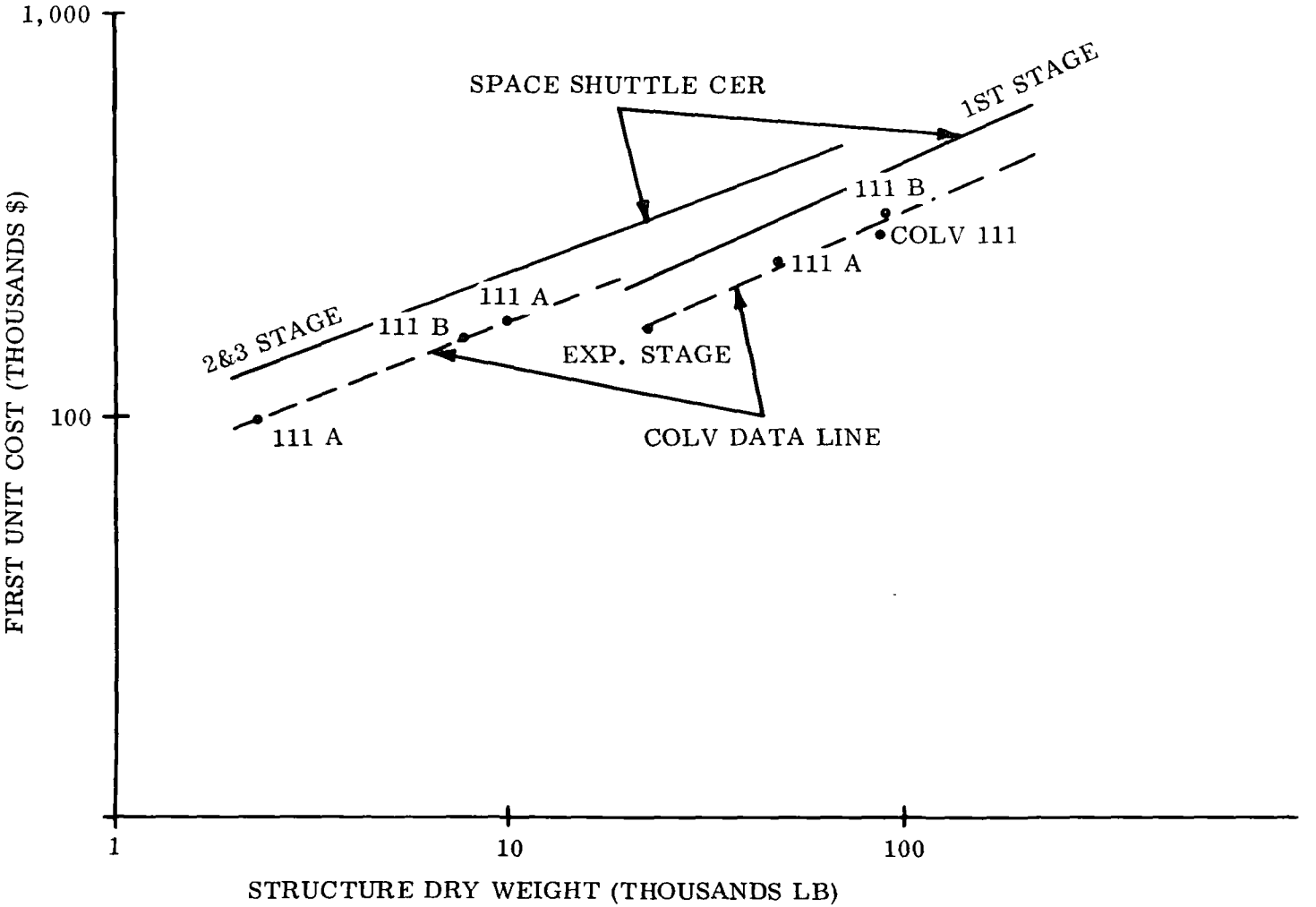


Figure 3.3-2. Pressure Fed Storable Structure

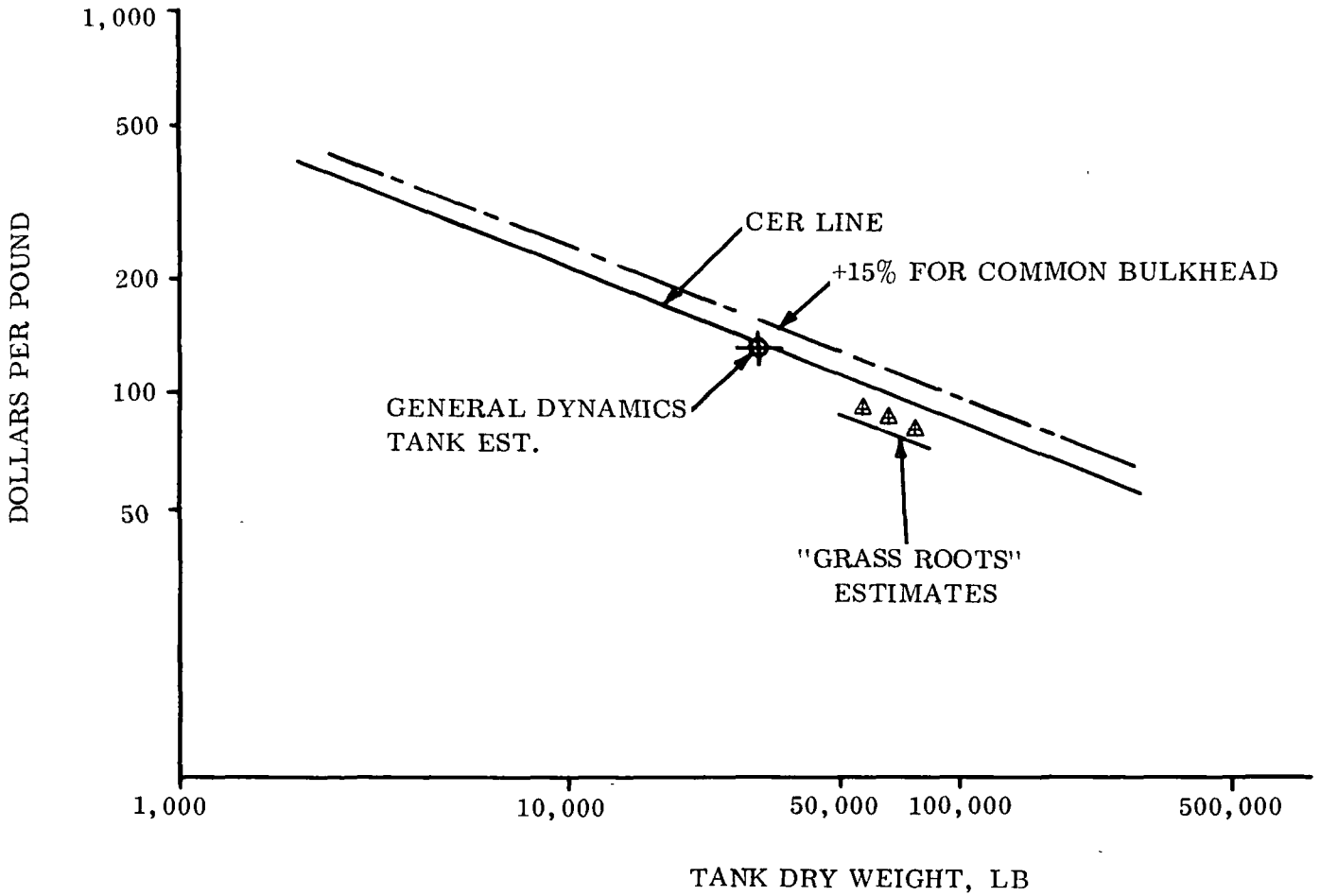


Figure 3.3-3. Strap-On Tank Cost

installation. Instrumentation and allowances for contingencies present other minor variances. In total, the General Dynamics tank cost estimates, on a dollar per pound basis, plots very close to the CER (reference Figure 3.3-3).

Due to the criticality of tank weight on the size of the A-1 configuration, every effort was made to reduce the tank weight, including use of a common bulkhead between the LH_2 and LO_2 tanks rather than separate tanks. To account for this additional design effort, the A-1 tank costs were increased by 15% as shown in Figure 3.3-3.

3.3.4 Thermal Protection System

The CER's for the thermal protection system (TPS) evolved from detailed engineering and manufacturing estimates for each of the specific configurations. Initial attempts to utilize existing Boeing and Grumman CER's highlighted their inadequacy to reflect differences such as main propulsion system crossfeed which, in the A configurations, have considerably more TPS penetrations than the others, and would require additional Engineering and Tooling (DDT&E).

The CER's for the TPS are:

	A1A	A3A	B	C-4
DDT&E (millions)				
Orbiter	162	146	120	120
Booster	-	-	-	112

1st Unit Cost (millions)

TPS Cost = TPS Area (sq. ft.) [% Ablative X \$150.
+ % Columbium X \$2200. + % Haynes X \$350.
+ % Rigid Insulation X \$200. + % Titanium X \$350.
+ % René X \$120. + % Thorium X \$450. + \$65*] X $\frac{1}{10^6}$

*Cost of Installation per sq. ft.

3.3.5 Propulsion Subsystem Preliminary Costs

Table 3.3-1 shows a summary of the Propulsion Subsystem in-house and vendor's costs estimated for the A-1, A-2 and C-4 Orbiter vehicles. For the A-1 and A-3 vehicles, costs given in this section include the core vehicles only. The propulsion subsystem was divided into five separate categories; the Main Propulsion Feed System (MPS), the Main Engines, the Attitude Control Propulsion System (ACPS), the Orbit Maneuvering System (OMS), and the Cruise Propulsion System (CPS) or airbreathers. The MPS costs include only lines, valves, connections, etc. Main engine costs have been listed separately and the main tank estimates are given in paragraph 3.3.8. The ACPS, OMS and CPS costs, however, include engines and tankage in addition to feed system components.

The following paragraphs describe the configurations costed and methods used in deriving these costs.

Configuration Description

Table 3.3-2 is a summary description of each configuration costed. A more detailed description of each is given in Part 2 of this report. As shown in Table 3.3-2, the major differences between the vehicles are in the Main Propulsion Feed System. The number of thrusters required in the ACPS and its turbomachinery size also differ between vehicles according to injection weight variations. As noted, for the A vehicles, 28 thrusters are used and for the C-4 vehicle, 22 thrusters are used on the orbiter and 34 on the booster. Similarly, CPS air breather engine requirements have not been considered for the A vehicles or the C-4 Orbiter. For the C-4 booster, six air breather engines have been assumed. For OMS, a common system was assumed for all vehicles.

Vendor's Parametric and Fixed Point Cost Information

Parametric curves representing preliminary vendor estimates for DDT&E and first unit costs are given in Figures 3.3-4, -5 and -6 for valves/disconnects, tanks and flexible joints/lines, respectively. The information used in developing the valve curve was provided by the Parker Hannifin Co. It represents applying scaling factors on 6- to 10-inch diameter valves since little information is available on valves in the 20- to 30-inch diameter range. Tank cost represented by Figure 3.3-5 are

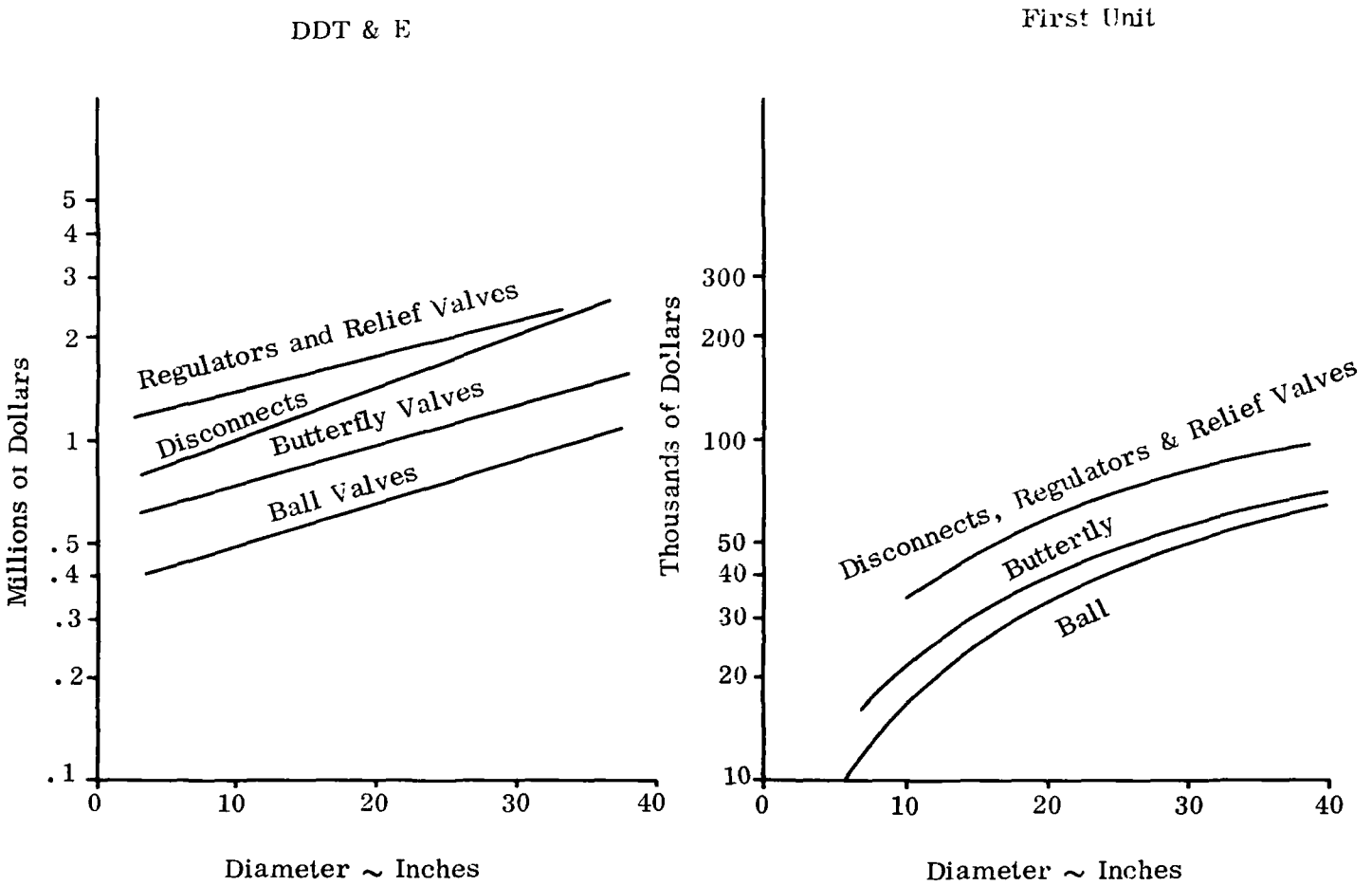


Figure 3.3-4. Valve and Disconnect Costs

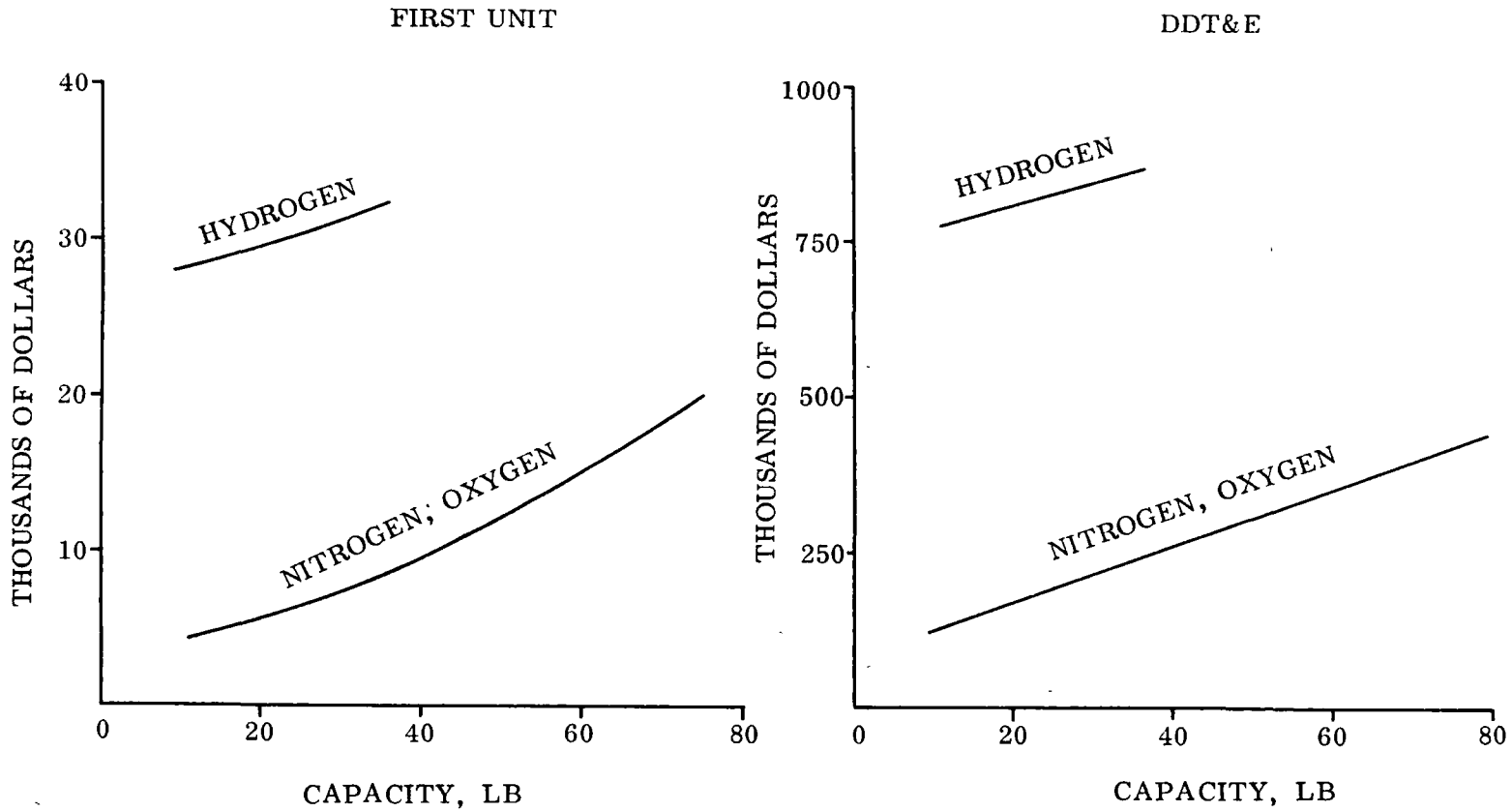
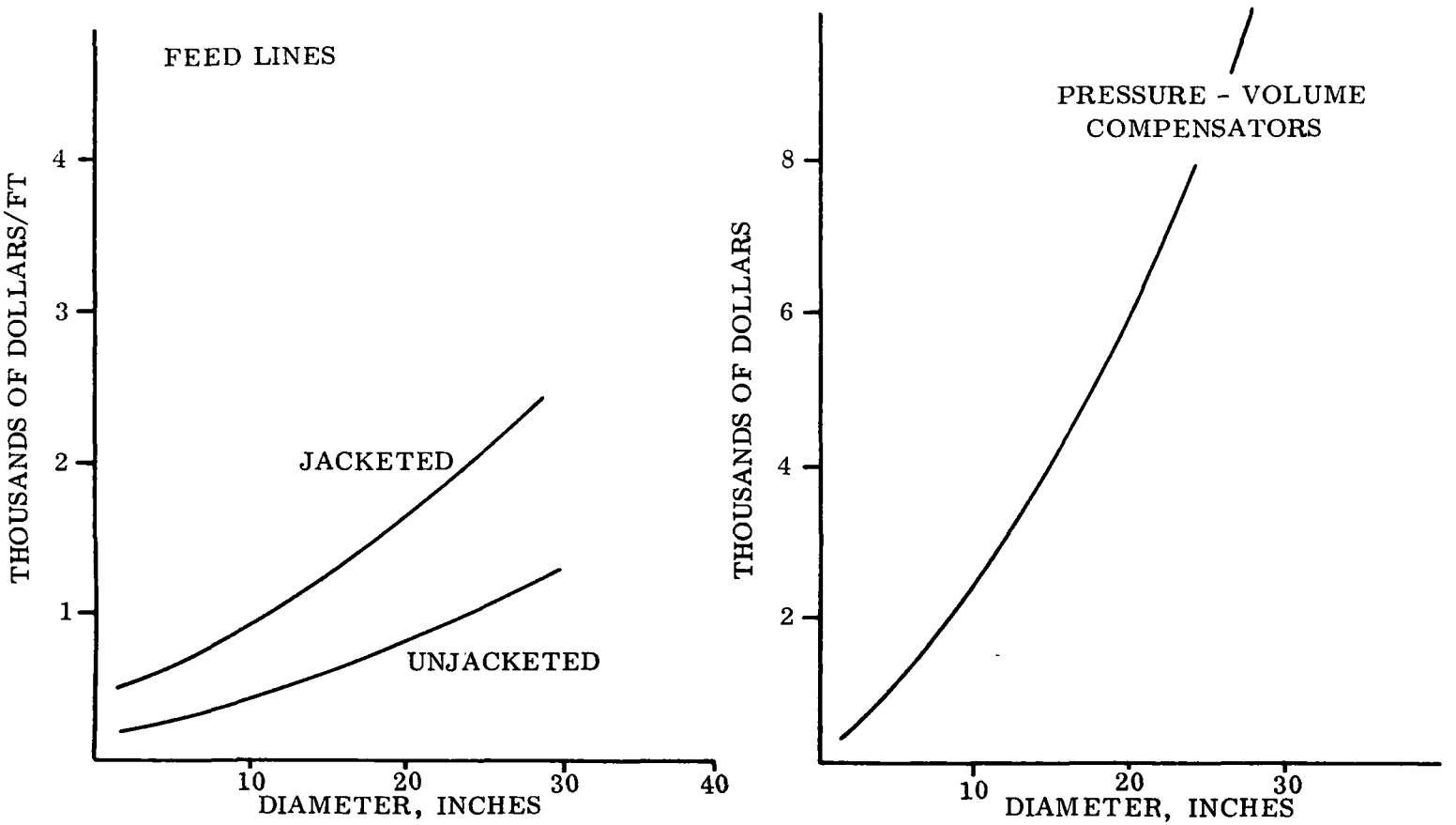


Figure 3.3-5. Gaseous Storage Tank Costs



NOTE: DDT&E COSTS FOR A REPRESENTATIVE SECTION OF LINE IS ESTIMATED AT $150 K EACH

Figure 3.3-6. First Unit Feed Lines/Flexible Joints Costs

based on a combination of fixed design point information provided by Aerojet General and LM cost data available on tanks in the size category shown. The data in defining the costs for flexible joints and feed lines was obtained from the Stainless Steel Products Company and is based on lines developed for the Saturn S-II and S-IVB stages. The curve representing feed lines includes a factor for flexible ball joints. More costly pressure-volume compensators (PVC's) are given separately.

Table 3.3-3 shows preliminary fixed point design costs for various components. Data source and assumptions related to each are also given. Costs shown are vendor supplied except for the OMS engine where the value shown is based on an assessment of historical cost information on the development and qualification of the RL10 family of engines.

In arriving at total system costs, some of the vendor information given in Figures 3.3-4, -5 and -6 and Table 3.3-3 was not used directly, but adjusted to include in-house contractor engineering and production costs.

In-House Cost Estimation

The relationship of Propulsion Subsystem "in-house" costs to procurement costs was developed using LM historical data. The information gathered was adjusted to allow for the fact that the EOS Main Propulsion engines will be Government Furnished Equipment. Since LM Propulsion System engines were Contractor Furnished Equipment, the costs of the Ascent, Descent and RCS engines were deleted from LM procurement costs to arrive at a base that is consistent with the costs expected to be incurred on EOS. Following is a summary derivation of the LM in-house and procurement cost relationships:

TOTAL SUBSYSTEM COST*	370.6
TOTAL PROCUREMENT COST	285.1
TOTAL IN-HOUSE COSTS	85.5 M
TOTAL ENGINE COST	219.2
PROCUREMENT COSTS LESS ENGINES	65.9

$$\frac{\text{IN-HOUSE COSTS}}{\text{PROCUREMENT COST}} \quad \frac{85.5}{65.9} = \quad 1.32 \approx 1.4$$

*Includes Ascent, Descent, RCS and White Sands costs.

For total procurement cost, 1.0 must be added to the derived 1.4 to account for procurement costs. The total factor then becomes 2.4.

Derivation of Cost Estimating Relationships

Main Propulsion Feed System: The Main Propulsion Feed System cost estimating relationships were derived: a) from hardware vendor's cost data, and b) an apportionment of in-house costs to vendor's costs. Vendor's cost information typical of that given in Figure 3.3-4, which shows valve and disconnect DDT&E and first unit costs as a function of diameter, was used to derive cost from a baseline system hardware list. Vendor cost information was also used to relate costs parametrically with thrust by assuming that the feed system diameter varies as the square root of thrust. Using the contractor cost/vendor cost ratio, in-house contractor costs were then determined. It is significant to note that the cost used in determining this ratio included engineering and production but not GSE Operations and Facilities. K_d is the baseline system cost factor (given in Table 3.3-4). The thrust term exponent represents the general shape of vendor's cost curves and the diameter/thrust relation assumed. Based on the above costing approach, the following estimating relationships were derived in terms of millions of dollars:

$$\text{DDT\&E Cost} = 2.4\, K_d \left[\frac{\text{Thrust}_{\text{S. L.}}}{\text{Thrust Base}_{\text{S. L.}}}\right]^{.2}$$

$$\text{First Unit Cost} = 2.4\, K_p \left[\frac{\text{Thrust}_{\text{S. L.}}}{\text{Thrust Base}_{\text{S. L.}}}\right]^{.4}$$

Main Propulsion System Engine: Main Propulsion System reusable cryo-engine costs were calculated using relationships derived by R. Krueger of the Aerospace Corporation for historical data including the Thor, J2, F1, H1, Agena, Rl10 and the Titan and Atlas series. The cost estimating relationships used are as follows in terms of millions of dollars:

$$\text{DDT\&E Cost} = 4.62 \left[\text{Thrust}_{\text{VAC}}\right]^{.38}$$

$$\text{First Unit Cost} = 3.3 \times 10^{-6} \left[200{,}000 + 7.05\,(\text{Thrust}_{\text{VAC}})\right]^{.904}$$

It is significant to note that engine integration in-house costs have been included as part of the feed system baseline system cost listed in Table 3.3-1. These costs were derived using a rough order of magnitude task breakdown estimate.

The first unit costs for the expendable pressure fed storable engine used in B2D are shown by the CER in Figure 3.3-7. This CER includes costs for the injector, shell, ablative liner, nozzle, skirt and all material burdens and installation costs. The engine cost data used for this program and for the MCD/SLV program were obtained from the Aerospace Corporation and the Air Force (SAMSO).

Supplier cost estimates have been compared to the CER and in general, they fall below the CER line.

Attitude Control Propulsion System: The Attitude Control Propulsion System costs for the baseline configuration were derived from vendor cost information in a manner similar to the Main Propulsion Feed System derivation. In deriving a parametric relationship between cost and vehicle configuration, however, variations of the Aerospace Corporation rocket engine cost estimating relationship were used. This was done because the major cost items in the ACPS, namely, the thruster and turbomachinery are equivalent in type to main engine hardware. The following cost estimating relationships in millions of dollars were derived using Aerospace Corporation exponents:

$$\text{DDT\&E Costs} = 2.4\ K_d \left[\frac{\text{Injection Wt}}{\text{Injection Wt}_{\text{Base}}}\right]^{.380}$$

$$\text{First Unit Costs} = 2.4\ K_{p_f} \left[\frac{\text{Injection Wt}}{\text{Injection Wt}_{\text{Base}}}\right]^{.90} + K_{p_e} \left[\frac{\text{No. of ACPS Engines}}{\text{No. of ACPS Engines}_{\text{Base}}}\right]$$

Again, the constant 2.4 accounts for in-house and vendor's costs and K_d, K_p and K_{p_e} are baseline DDT&E, first unit feed system, and engine costs respectively.

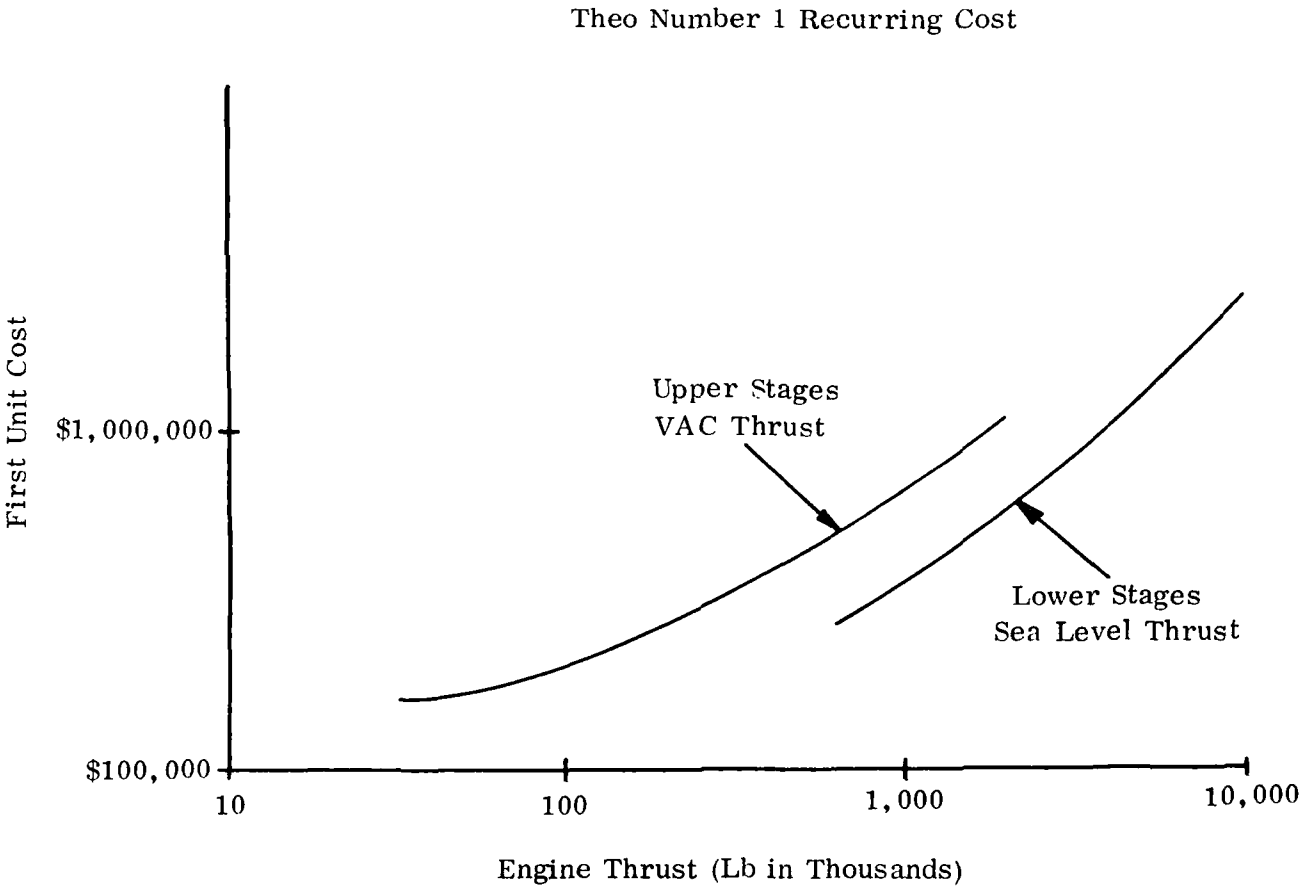


Figure 3.3-7. Pressure Fed Engines Cost Estimating Relationship

Orbit Maneuvering System: OMS costs were derived in a manner similar to the Main Propulsion Feed System for a fixed baseline design only. Baseline costs are given in Table 3.3-1. As mentioned above, engine costs are based on vendor provided historical data. Integration costs are derived by a ROM task breakdown estimate.

Cruise Propulsion System: Cruise Propulsion System costs were derived in a manner identical to OMS.

TABLE 3.3-1. PROPULSION SUBSYSTEM COST SUMMARY (MILLIONS OF DOLLARS)

	DDT&E				First Unit			
	A1	A3	C-4 Orb	C-4 Boost	A1	A3	C-4 Orb	C-4 Boost
MAIN PROPULSION FEED SYSTEM	64	50	32	37	20	11	7	15
MAIN ENGINES	745	656	654	-	48	15	7	43
ATTITUDE CONTROL PROPULSION SYSTEM	274	212	222	74	9	6	6	12
ORBIT MANEUVERING SYSTEM	111	111	111	-	4	4	4	-
CRUISE PROPULSION SYSTEM	-	-	-	100	-	-	-	5
TOTAL	1194	1029	1019	211	81	36	24	75

TABLE 3.3-2. SUMMARY DESCRIPTION OF COSTED CONFIGURATIONS

A1	MAIN	ACPS	OMS	CPS
Engines	12 at 470K (S. L.)	28 at 3.5K (VAC)	1 RL-10 Modified	-
Valves	70 at 2 to 12" Diam.	71 at 1/2 to 3-1/2" Diam.	36 at 1/2 to 2" Diam.	-
Lines	775 ft at 2 to 14" Diam.	820 ft at 1/2 to 3-1/2" Diam.	200 ft at 1/2 to 2" Diam.	-
Tankage	See Appendix M	111 cu ft Bellows Tanks	2000 cu ft Cryo Tanks	-
Turbomachinery	Part of Main Engine	H_2: 800 HP O_2: 170 HP	Part of ACPS	-
A3				
Engines	4 at 400 K (S. L.)	28 at 3.5K (VAC)		-
Valves	54 at 2 to 12" Diam.	71 at 1/2 to 3-1/2" Diam.		-
Lines	550 ft at 2 to 14" Diam.	820 ft at 1/2 to 3-1/2 Diam.	Same as A1	-
Tankage	See Appendix M	111 cu ft Bellows Tanks		-
Turbomachinery	Part of Main Engine	H_2: 330 HP O_2: 68 HP		-
C-4 Orb				
Engines	2 at 458 K (VAC)	22 at 3.5K (VAC)		-
Valves	44 at 1 to 14" Diam.	71 at 1/2 to 3-1/2" Diam.		-
Lines	800 ft at 1 to 20" Diam.	1040 ft at 1/2 to 3-1/2 Diam.	Same as A1	-
Tankage	See Appendix M	111 cu ft Bellows		-
Turbomachinery	Part of Main Engine	H_2: 410 HP O_2: 86 HP		-
C-4 Boost				
Engines	*12 at 382 K (S. L.)*	*26 at 3.5K (VAC)* *8 at 1.5K (VAC)*	-	*6 Engines*
Valves	22 at 2 to 25" Diam.	22 at 1 to 7" Diam.	-	42 at 1 to 3-1/2" Diam.
Lines	5000 ft at 2 to 25" Diam.	1200 ft at 1 to 7" Diam.	-	200 ft at 1 to 3-1/2" Diam.
Tankage	See Appendix M	1062 cu ft Cryo Tanks	-	470 cu ft Cryo Tank
Turbomachinery	Part of Main Engine	-	-	16 HP Boost Pump

TABLE 3.3-3. PROPULSION SUBSYSTEM FIXED DESIGN POINT VENDOR COST DATA
(MILLIONS OF DOLLARS)

ITEM	RDT&E	FIRST UNIT	SOURCE
ACPS			
Bellows Tanks	5.5	.1	Bell Aerospace
Thrusters	35	.08	Aerojet General
Turbopumps	20	.2	
Heat Exchangers	9	.02	
Gas Generators	4	.05	
CPS			
Modified JTF-22B Engine*	75	4.5	Pratt & Whitney
Engine Installation and Tankage	25	.5	In-House Estimate
OMS			
Modified RL-10 Engine**	50	.5	Pratt & Whitney (Adjusted)
Engine Installation and Tankage	61	3.5	In-House Estimate
MAIN PROPULSION			
Engine	Derived from Aerospace Corporation (Refer to Section 3.3.8)		
Engine Installation and Tankage			

*Modified for H_2 Conversion

**Modified for Life

TABLE 3.3-4. BASELINE COST DATA

		A1	A3	C-4 Orbiter
MPS	DDT&E K_D	25	25	11.25
	FIRST UNIT K_P	7.36	6.88	2.76
	BASELINE THRUST ~ LBX10^{-6}	4.62	4.62	.80
MPS ENGINE	VACUUM THRUST			
ACPS	DDT&E K_D	104		
(BASELINE INJECTION WT: 240K)	FIRST UNIT K_{P_F}	3.24		
(BASELINE NO. OF ENGINES: 28)	K_{P_E}	2.24		
	INJECTION WT ~ LB	Variable		
	NO. OF ENGINES	28	28	22
OMS	DDT&E/FIRST UNIT			
	ENGINES ~ \$X10^{-6}	50/.5		
	TANKS ~ \$X10^{-6}	40/.5		
	VENDORED HDWE ~ \$X10^{-6}	8/.7		
	IN-HOUSE ~ \$X10^{-6}	11/2.2		
	ENGINE INTEGRATION ~ \$X10^{-6}	2/.1		

TABLE 3.3-4. BASELINE COST DATA (Cont)

		A1	A3	C-4 Orbiter
CPS	DDT&E/FIRST UNIT			
	ENGINE (CONVERSION TO H_2) ~ $\$X10^6$	75	→	
	TANKS ~ $\$X10^6$			
	VENDORED HDWE ~ $\$X10^6$			
	IN-HOUSE ~ $\$X10^6$	25		
	ENGINE INTEGRATION ~ $\$X10^6$			

3.3.6 Avionics/Power/ECLSS

Per contract, all costs for this category were supplied by NASA. The costs were applicable to the two-stage fully reusable concept addressed in the Phase B Study contracts. To apply this data to the varied configurations of the alternate space shuttle study, it was necessary to re-examine the requirements of each configuration and adjust the NASA supplied costs to reflect the system differences.

Table 3.3-5 shows the qualitative basis for the avionics adjustment. Note that the C orbiter is the baseline from which all adjustments are made. Tables 3.3-6 and -7 list adjusted DDT&E and production costs for the avionics/power/ECLSS subsystems.

Table 3.3-8 compares NASA's initial DC-3 (space shuttle) cost data with their revised data base typified by Phase B subsystem designs.

3.3.7 Vehicle Refurbishment

The CER's for vehicle refurbishment are divided into two categories:

1) Replenishment Spares - consisting of vehicle systems, TPS refurbishment material, RCS and Propulsion system hardware, and miscellaneous support hardware.

2) Overhaul - consisting of airframe rework, airbreather engine overhaul, and rocket engine overhaul.

Vehicle system and miscellaneous support hardware CER's estimate these requirements at the organizational and intermediate level of logistic support, while airframe rework and airbreather engine overhaul estimate at the depot level. Both are based on Navy (OPNAV 90P-02 "Navy Program Factors") and in-house estimates, and cover scheduled and unscheduled maintenance hardware only. The rocket engine overhaul CER is based on the NASA Space Task Group Report, and RCS and propulsion system refurbishment is from the "Space Planners Guide".

TABLE 3.3-5. DC-3 AVIONICS HARDWARE/SOFTWARE/FUNCTIONAL DIFFERENCES

Concept Subsystem	A	B	C	
			Orbiter	Booster
Displays and Cont.	No change	No change	REFERENCE	80% of DDT&E within orbiter 20% Integ & Interface
Communication	Increase - tracking XPDR, strap-on, telemetry	Increase - tracking XPDR, booster telemetry		• As above plus • Antenna patterns & installation
G N & C	Increase - software, sensors, strap-on control	Increase - software sensors, interface electronics		• As D&C plus • Software & NAV-AIDS.
Data Mgmt. & Inst.	Increase - software MSMNT, points, cross feed, engine interfaces	Increase - software booster interfaces		• As D&C plus • Software
Elec. Pwr. Conv. & DIST.	No change	No change		• As D&C
Control Act.	Increase - delta wing	No change		• No change

TABLE 3.3-6. DC-3 AVIONICS COSTS

Subsystem	(Costs In Million $)						
	DC-3 Avionics (8/19/70)		Updated DC-3 Avionics				
			Concept A	Concept B	Concept C		
	Orbiter	Booster			Orbiter	Booster	
						3-Month	Mid Term
DDT&E							
Displays & Cont.	33	21	33	33	33	7.3	15.3
Communication	95	62	99	99	95	22.5	47.1
G N & C	203 (2)	131 (2)	214	214	203	62	130.0
Data Mgmnt. & Instrum.	167 (2)	109 (2)	184	177	167	54	113.1
Elect. Pwr Conv. & Distrib.	8	6	8	8	8	2	4.2
Control ACT.	14	9	16.8	14	14	14	29.3
Total (1)	520	338	554.8	545	520	161.8	339
UNIT PRODUCTION							
Displays & Controls	7.7	7.7	7.7	7.7	7.7	7.7	
Communications	6.2	6.2	6.6	6.6	6.2	6.2	
G N & C	30.5	30.5	31.5	31.0	30.5	29.1	
Data Mgt. & Inst.	17.2	17.2	18.2	17.7	17.2	16.0	
Elect. Pwr Conv. & Dist.	0.9	0.9	0.9	0.9	0.9	0.9	
Control Act.	1.5	1.5	1.8	1.5	1.5	1.5	
Total	64.0	64.0	66.7	65.4	64.0	61.4	

NOTES: (1) High pressure engine control computers are not included. If other engines are used, add $\$15 \times 10^6$ for DDT&E and $\$0.5 \times 10^6$ per engine for production costs.

(2) The sum of these costs appears excessive.

TABLE 3.3-7. POWER AND ECLSS COSTS

Subsystem	DDT&E			1st Unit Production		
	Orbiter		Bstr.	Orbiter		Bstr.
	A3	B&C-4	C-4	A3	B&C-4	C-4
POWER						
APU	14.6	14.6	9.3	1.61	1.61	2.30
Batteries/Fuel Cells/ Alternators	25.5	25.5	1.7	2.08	2.08	0.44
Cryogenic	11.9	10.8	10.0	1.7	1.7	0.9
ECLS	60.0	60.0	14.0	1.8	1.8	0.7

TABLE 3.3-8. NASA SUBSYSTEM COSTS

	DC-3 Subsystems		Phase B Subsystems*		
	DDT&E w/o Test Unit	Unit Cost	DDT&E w/3 Test Units	DDT&E w/o 3 Test Units	Unit Cost
Orbiter					
Avionics	520	64	500	425	25
Power	339	5.4	120	90	10
ECLSS	60.	1.8	100	70	10
Booster					
Avionics	339	61	600	540	20
Power	21	3.6	130	100	10
ECLSS	14	0.7	40	25	5

*NASA/MSC LTR-EA9-A9-70-1110-2

The CER's are summarized below:

- $\frac{\text{Vehicle Systems}}{\text{Flt}} = (9.8 + .00072\ W_{empty} + .055\ W_{eltrncs}) \times \frac{HR}{FLT}$

- $\frac{\text{TPS Refurb.}}{\text{Flt}} = (\text{ft}^2 \text{ TPS Area}) \times \sum_{(1)}^{n} \frac{(\%\ \text{iTH Matrl Area})\ (\text{ith Matrl } \$/\text{ft}^2 + \$65/\text{ft}^2 \text{ Insulation})}{\text{ith Matrl. No. of flights}}$

- $\frac{\text{RCS and Proplsn. Sys Hardware}}{\text{Flt}} = 0.1\ (\text{1st Unit Cost of Subsystem})$

- $\frac{\text{Miscellaneous Support}}{\text{Flt}} = (14 + .0007\ W_{liftoff} + .086\ W_{eltrncs}) \times \frac{HR}{FLT}$

- $\frac{\text{Airframe Rework}}{\text{Flt}} = \left[-65000 + 1.5\ W_{empty} + 2760 \left(\frac{HR}{FLT} \times \frac{1)}{12} \right) \right] \times 0.7^*$

- $\frac{\text{Airbreather Engine Overhaul}}{\text{Flt}} = \left[\left(112 + .00034\ W_{liftoff} - .086(50) \right) \frac{1}{50} \right] \times 0.7^*$

- $\frac{\text{Rocket Engine Overhaul}}{\text{Flt}} = 50{,}000 \frac{(\text{No. of RCS engines})}{50} + .012\ (\text{Total Thrust})$

3.3.8 Airframe

The Shuttle airframe CER, for the reusable vehicles, is a set of airframe cost equations based on industry-wide data. Complete documentation of the CER is given in Planning Research Report (PRCR-547A). The cost estimates include:

- Airframe Manufacturing Planning Report (AMPR) cost
  1) Non-recurring Development
  2) Recurring Production (includes installation and checkout of subsystems)

---

*(0.7 Factor removes manpower)

- The cost for airframe

  1) Engineering & Tooling

  2) Manufacturing Direct Labor Incl. Q. C.

  3) Manufacturing Materials

The equations used to estimate airframe cost follow. They estimate costs for conventional aircraft. As a result, they must be modified for Shuttle design requirements. These modifications are discussed in Paragraph 3.3.8.3.

DDT&E (No Hardware)

- Cost Equation

  $C_{nr} = 1080.74 - 450.11 S_a^2 + 1119.2\ R$

  $Sa = M_{max}$ @ Altitude (Shuttle use M @max Q)

  $R = \frac{(We = Wa)}{Wa}$

  We = Wt Empty

  Wa = AMPR Weight

- Includes all airframe associated development cost

  1) Aircraft associated development design & test

  2) Tool & production planning

  3) Tool design and manufacturing

  4) Eng'g and tooling overhead

Sus. Engineering & Tooling Cost Equation

- $C_{e\&t} = -179.37 + 2.73\ D_n + 99.30\ \text{Log}\ T + 154.46\ R + 52.89\ S_a$

  D_n = Weight Growth Factor

  T = Time Factor

$R = (We - Wa)/Wa$

We = Weight Empty

Wa - AMPR Weight

$S_a = M_{max}$ @ Altitude

- Includes:

  1) All eng'g and tooling effort associated with design changes

Mfg Direct Labor Cost Equation

- $C_{dl} = -5.02 + 4.508\ S_s^{2} + 12.832\ P_n^{-.5} + 554.07\ W_a^{-.5} + .325\ D_n^{.5}$

  $S_s = M_{max}$ @ S. L.

  P_n = Delivery Rate

  W_a = AMPR Weight

  D_n = Weight Growth Factor

- Includes

  1) Fabrication, sub and final assembly (AMPR)

  2) Q. C.

  3) Installation test and checkout of subsystems

Mfg. Materials Cost Equation

- $C_{mm} = -18.75 + 21.58\ S_a + .724T - .0176\ W_a^{.5} + 21.12\ P_n^{-.5}$

  $S_a = M_{max}$ Altitude

  T = Time Factor (Y-1940)

  (Tech. Inflation Factor)

  W_a = AMPR Weight

  P_n = Delivery Rate

- Includes

    1) Materials

    2) Purchased parts

    3) Airframe installed equipment

3.3.8.1 CER Characteristics

Table 3.3-9 lists the range of values used to derive the coefficients for the independent variables that make up the CER's. For example, the AMPR weight for the C-4 Orbiter is 117,000 pounds, or slightly higher than the maximum value (B-52) of the model input data. Booster AMPR weight is substantially higher; however, its structural design will be less complex than the Orbiter and subject to less uncertainty when extrapolated beyond the model input data. The Shuttle values for the other variables are all within the range of the input data, therefore making the model appropriate for Shuttle airframe cost estimating purposes.

Some explanation of the speed variable is necessary since the ΔV required for staging and orbit are orders of magnitude greater than the maximum speed of Mach 2.23 listed for the CER input data. The rationale used to select Shuttle V_{max} is to determine Mach Number at maximum dynamic pressure. It is at this point during liftoff that the structural design is taxed the most. The very high Shuttle ΔV values are achieved in very low density atmosphere, thus limiting the loading across the structure. Maximum Q varies with configuration, occurring at approximately Mach 1.1. Since this is well within the range of the CER input data, those cost equations having a speed of altitude variable can be used for estimating Shuttle structure cost.

Also listed in Table 3.3-9 are statistical data used to evaluate the CER's. These include:

- Multiple Correlated Coefficient - This is a measure of association between the dependent and independent variables. Values of 90% or greater are recorded for the R-547A equations indicating strong association

TABLE 3.3-9. PLANNING RESEARCH CORPORATION (PRC R-547)
AIRFRAME COST MODEL CHARACTERISTICS

	Manufacturing Direct Labor				Mfg Mats. & Procured Equip				Engineering & Tooling			
		MAX	MIN	AVE		MAX	MIN	AVE		MAX	MIN	AVE
Independent Variable	S_s	1.5	.30	.73	S_a	2.23	.54	1.16	S_a	2.23	.54	1.17
And	P_n	14.8	1.0	4.14	P_n	27.5	3.0	13.1				
Range Of Model Input	W_a	112,176	2,509	23,635	W_a	112,176	4114	26,452	$W_a^{(1)}$	112,176	4114	21,698
Data					T	18.0	4.0	12.8	T	18.0	4.0	13.2
									$W_e^{(1)}$	17,456	6,398	33,748
									D_n	18.4	0	5.36
Statistical Data	Mult. Corr. Coef. = .958				= .927				= .90			
	Std. Error (S) = .464				= 3.78				= 6.00			
	Coef of Var = 12.5%				= 10.2%				= 24%			
	90% Pred Interval = $\overline{X}$±22%				= $\overline{X}$±39.5%				= $\overline{X}$±43%			

List of Symbols:

S_s = Speed @ Sea Level (Mach No.)

S_a = Speed @ Altitude (Mach No.)

P_n = Production Rate

W_a = AMPR Wt

W_e = Weight Empty

T = Year of First Delivery

D_m = Weight Growth Factor

$R^{(1)}$ = Installed Equip. Ratio

Note: (1) W_a and W_e used to establish $R = \frac{W_e - Wa}{Wa}$

- Standard Error - This is a measure of dispersion of the observed points about the regression surface. The smaller the standard error, the greater the reliability of the estimate. The standard error is used to calculate prediction intervals for the CER's. They are given in absolute numbers and as such are difficult to evaluate. This is remedied by estimating the coefficient of variation

- Coefficient of Variation - By relating the standard error to the mean of the dependent variable input data, a relative dispersion results which can be used to compare the estimating reliability of individual equations. Values less than 20% are considered desirable

These are not the only statistical measures that are important. A complete statistical analysis, however, is not the objective of this section.

3.3.8.2 CER Sensitivity Analysis

To interpret the results of cost estimating relationships properly, it is useful to know which inputs are most important in establishing the estimated cost. One measure of sensitivity is to determine the change in the estimate when the value of each input variable is changed by a constant percentage. Table 3.3-10 shows the sensitivity of the input variables for: manufacturing direct labor, manufacturing materials, sustaining engineering and tooling.

In Table 3.3-10 the higher the slope value the more sensitive the variable is to change. A positive sign indicates that cost increases directly with an increase in the variable; a negative sign, an inverse relationship. The essence of these relationships is also summarized in qualitative terms in Table 3.3-10.

Figure 3.3-8 shows the contribution of each variable to orbiter cost. The main contributors are:

1) First Flight Date - A variable that accounts for the "technological inflation" that accompanies advancing technology.

2) Production Rate - This is particularly important for very low production quantities and rates.

TABLE 3.3-10. INPUT VARIABLE SENSITIVITY

	Variable	Slope	Principal Cost Determinants
Mfg Direct Labor	S_s	1.5	1) Speed variable most sensitive to change
	W_a	- .05	2) Prod. rate variable major contributor to cost (Figure 3.3.11-1).
	P_m	- .062	
	D_n	.05	
Mfg. Mat & Purch Equip	S_a	.612	1) Speed variable most sensitive to change
	P_m	.043	
	W_a	- .043	2) Mach No., production rate and time variable major cost contribution (Figure 3.3.11-1).
	T	.158	
Sust. Eng. & Tooling	S_a	.475	1) Speed and Equipment weight most sensitive to change
	R	.40	
	T	.091	2) Mach No., and time variable major cost contributors (Figure 3.3.11-1).
	D_n	.125	

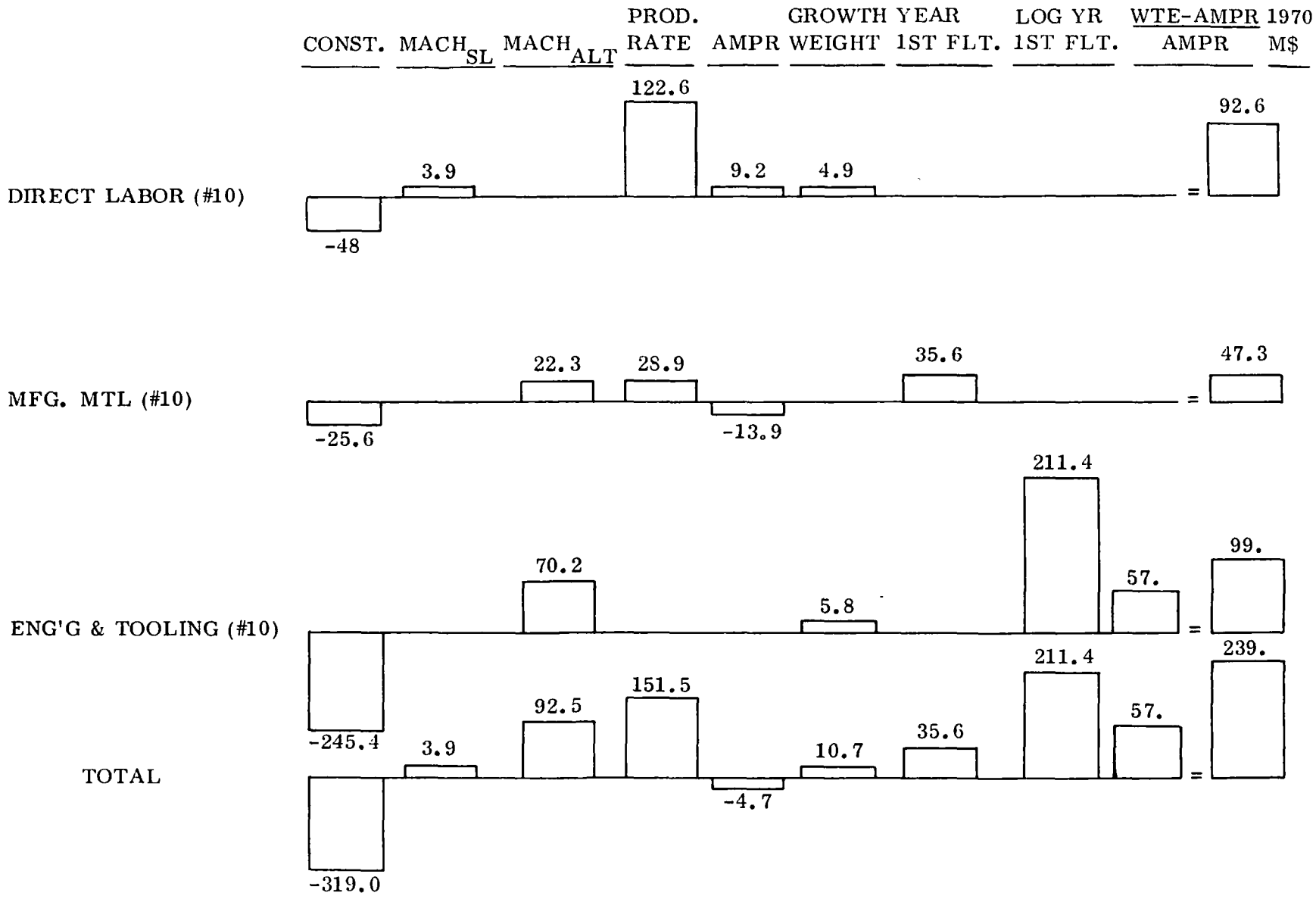


Figure 3.3-8. PRC Airframe Equations Sensitivity Analysis (Unit 10)

3) Mach Number - A proxy for the technological level associated with a given performance.

The weighting of these variables change as the quantity of vehicles estimated increases. However, since the Shuttle vehicle quantities will remain relatively small, estimates for unit 10, extrapolated back to unit 1, give representative Shuttle costs.

Figures 3.3-9 to -12 illustrate the degree of accuracy, or inaccuracy, associated with the individual airframe CER's. The DDT&E and Recurring Engineering and Tooling equations show reasonable agreement between estimate and actual.

The C-4 Orbiter estimate is plotted to illustrate the cost estimate in relation to aircraft used to derive the CER. The C-4 cost per pound is estimated lower than the relatively small, high-performance B-58, and higher than the larger, slower-performance aircraft.

The Manufacturing Labor and Materials equations illustrate a wider dispersion of estimate vs actual. This is the result of the high degree of uncertainty associated with estimating low production quantities. The model input data reflect this, resulting in lower estimating accuracy.

Of particular interest is the higher estimated value for the B-52 than was actually experienced. The B-52 had a very low production rate at the low quantities. The manufacturing direct labor equation being sensitive to production rate (Figure 3.3-8) estimated the B-52 cost higher than the actual value. It is also noted that the C-4 estimate is substantially higher than the other vehicles listed in the figure. The same low production rate is working on the C-4. The estimate, as a result, may be on the high side. The degree of conservatism may be warranted, however, since unforeseen technological problems may, in fact, require a greater manufacturing effort.

The output of the airframe CER is characteristic of conventional aircraft. The Shuttle, however, requires that cost estimates reflect a somewhat different technology. Accounting for the new technology by means of CER modifications is discussed in the following paragraph.

3.3.8.3 CER Modifications

The Shuttle modifications to PRC R547-A include:

- Titanium Cost Factor
- Cryogenic Tank Cost
- Fuel Feed System Cost
- Test and Checkout of Space Vehicle Subsystems

In order to derive a relative comparison of the development test requirements for aircraft and spacecraft, each of the Grumman Shuttle design sections were contacted. The results, presented in Table 1, indicated an increase of 53% in the test manhours required for Space Shuttle type vehicles over conventional aircraft. It was reasoned that the test manhours increase would be indicative of the increased complexity of the design and spec requirements. This factor was, therefore, applied to the engineering, tooling, manufacturing labor and materials costs defined by the PRC estimate for the airframe costs of a Space Shuttle vehicle based on its size and atmospheric performance.

The modifiers are summarized below.

Titanium Cost Factors

- Using mid-1970's technology, the following factors are derived:

  Mfg direct labor = 1.7 times equiv. PRC estimate

  Raw materials = 3.3 times equiv. Raw materials est.

  Tooling = 1.6 times equiv. PRC Estimate

Cryogenic Tank Factor

DDT&E = .10(.45) (PRC) (1.53) + CTD

1) .10 = that portion of total AMPR that is tankage

2) .45 = portion of DDT&E cost associated with design & dev.

3) PRC = base cost estimate from PRC cost model

4) 1.53 = complexity factor

5) 1.368= 1970 dollars

6) CTD = + $80M cyro tank development

Production = .10 (PRC) (1.53)

0.1 = Tankage weight fraction

1.53 = Complexity factor

1.368 = 1970 dollars

Tank Insulation

Cost = $200/ft^2 (area of tankage)

Fuel Feed System Cost

$$\text{DDT\&E} = 2.4 \left(\text{Kd} \left[\frac{\text{Thrust}}{\text{Baseline Thrust}} \right]^{.2} \right)$$

Kd - Baseline System Cost

Kd	$A_{1\&3}$	C_{orb}	C_{boost}
	$25 x 10^6	$11.25 x 10^6	$15 x 10^6

$$\text{PRODUCTION} = 2.4 \left(K_p \left[\frac{\text{Thrust}}{\text{Baseline Thrust}} \right]^{.4} \right)$$

K_d = Baseline System Cost

	A_1	A_3	C_{orb}	C_{boost}
K_p	\$7.36 x 10^6	\$6.88 x 10^6	2.76 x 10^6	6.0 x 10^6
Baseline Thrust	4.62 x 10^6	4.62 x 10^6	.80 x 10^6	4.8 x 10^6

(Data & equations are based on vendor data & Aerospace Corp. coeff. from Section 3.3.5).

Test & Checkout of Space Vehicle Subsystems

- AMPR Cost Distribution

  1) 40% for fabrication & minor assembly

  2) 40% for major & final assembly

  3) 20% for installation, test and checkout

     a) Approximately 1/2 of 20% for test & checkout

- Test & checkout for shuttle subsystems = 50% more difficult to perform than aircraft.

- AMPR Cost Factor for test and checkout is:

  $$F_{t\&c} = .5\ (.2\ C_{AMPR})\ (.5) = .05\ C_{AMPR}$$

  Note: Double the $F_{t\&c}$ factor to allow for contingency

- Therefore use 10% for added subsystem test & checkout

- Total AMPR cost - 1.10 (C_{AMPR})

The cost modifiers are applied to the PRC cost estimate as follows: The initial PRC estimate for DDT&E and production are first modified for titanium percentage.

Structure Cost

DDT&E

PRC Cost = C_{nr}

First Unit Cost (AL)

$$\text{PRC Cost} = C_{dl} \times 6.99 + C_{mm} + C_{e\&T}$$

Where 6.99 is the 1963 equivalent to a 9.56 1970 labor rate.

First Unit Cost with X% T1 structural weight

$$\text{PRC Cost} = 6.99\, C_{dl}\ 1.7 \times .67 \times X\%\ \text{Ti} + (1 - .67\ X\%\ \text{Tl})$$

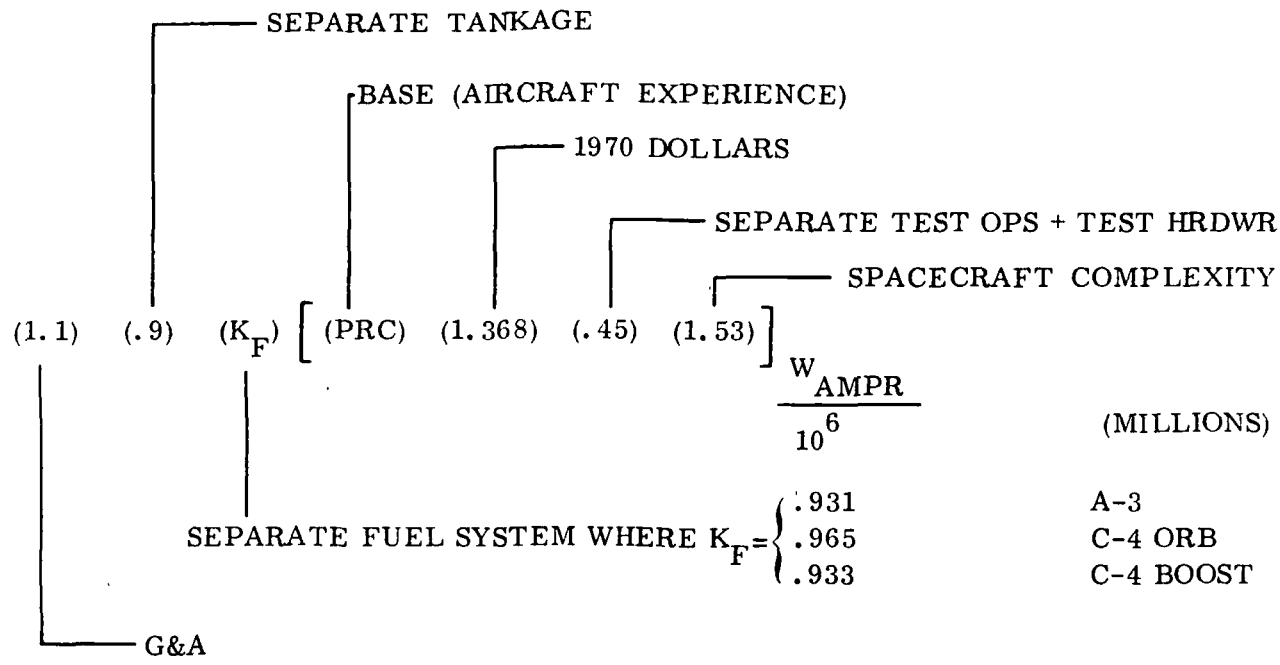
$$+ C_{mm}\ 3.3 \times .67 \times X\%\ \text{Ti} + (1 - .67 \times X\%\ \text{Ti})$$

$$+ C_{e\&T}\ 1.6 \times .67 \times X\%\ \text{Ti} + (1 - .67 \times X\%\ \text{Ti})$$

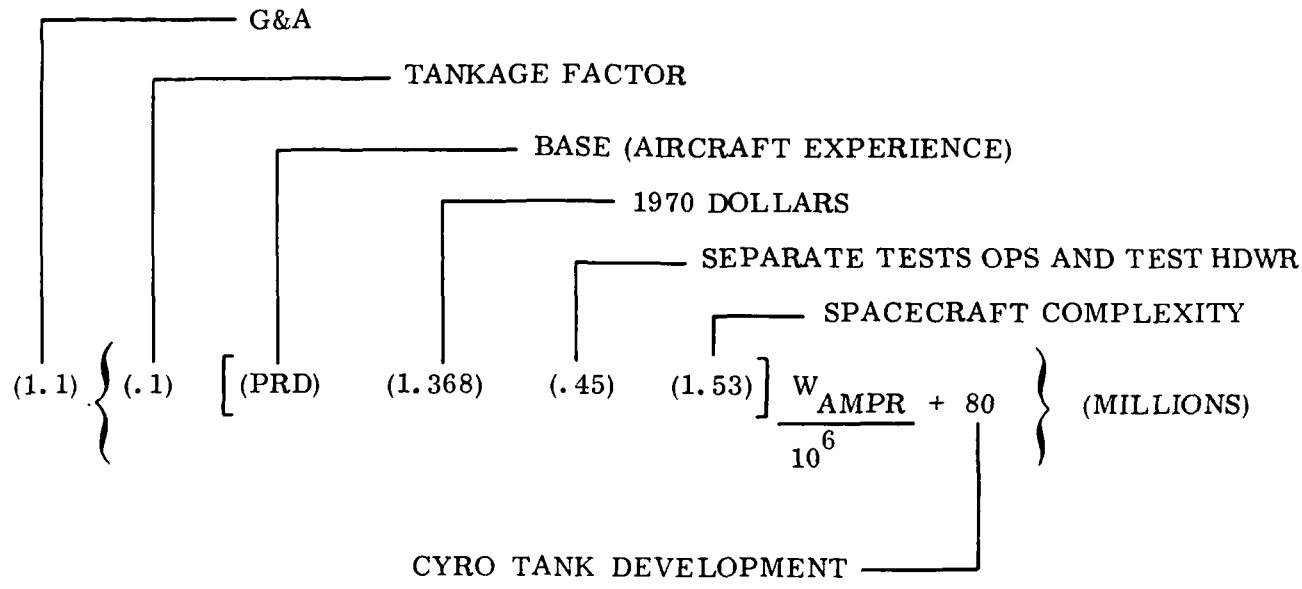
(Note: Structural Weight = 0.67 x AMPR weight)

These costs are then modified to account for the difference in concepts as well as the variation of configurations within concepts. Airframe design and development and first unit production costs are arrived by means of the algebraic expressions listed below.

AIRFRAME DESIGN AND DEVELOPMENT



TANKAGE DESIGN AND DEVELOPMENT



AIRFRAME PRODUCTION AT UNIT #10

$$(1.1)\ (1 - .1 - K_F)\ [(PRC)\ (1.368)\ (1.1)]\ \frac{(W_{AMPR})}{10^6}$$

- (1.1): G&A
- $(1 - .1 - K_F)$: SEPARATE TANKAGE
- (PRC): BASE (AIRCRAFT EXPERIENCE)
- (1.368): 1970 DOLLARS
- (1.1): CHECKOUT FACTOR
- K_F: SEPARATE FUEL SYSTEM WHERE $K_F = \begin{cases} .069 & \text{A-2} \\ .035 & \text{C-4 ORB} \\ .067 & \text{C-4 BOOST} \end{cases}$

TANKAGE PRODUCTION AT UNIT #10

$$(1.1)\left((1.368)\ (.1)\ [(PRC)\ (CF)\ (1.1)]\ \frac{W_{AMPR}}{10^6} + [\$200/SQ\ FT_{H_2}\ TANK]\ AREA_{H_2} \right)$$

- (1.1): G&A
- (1.368): 1970 DOLLARS
- (.1): TANKAGE FACTOR
- (PRC): BASE (AIRCRAFT EXPERIENCE)
- (CF): COMPLEXITY FACTOR $\begin{cases} 2.67 & \text{A3A} \\ 2.80 & \text{C4 BSTR} \\ 3.10 & \text{C4 ORB} \end{cases}$
- (1.1): CHECKOUT FACTOR
- $\$200/SQ\ FT_{H_2}\ TANK$: CYRO TANK INSULATION

MULTIPLY ABOVE EQUATIONS BY 1.36 TO CONVERT TO UNIT #1 COSTS.

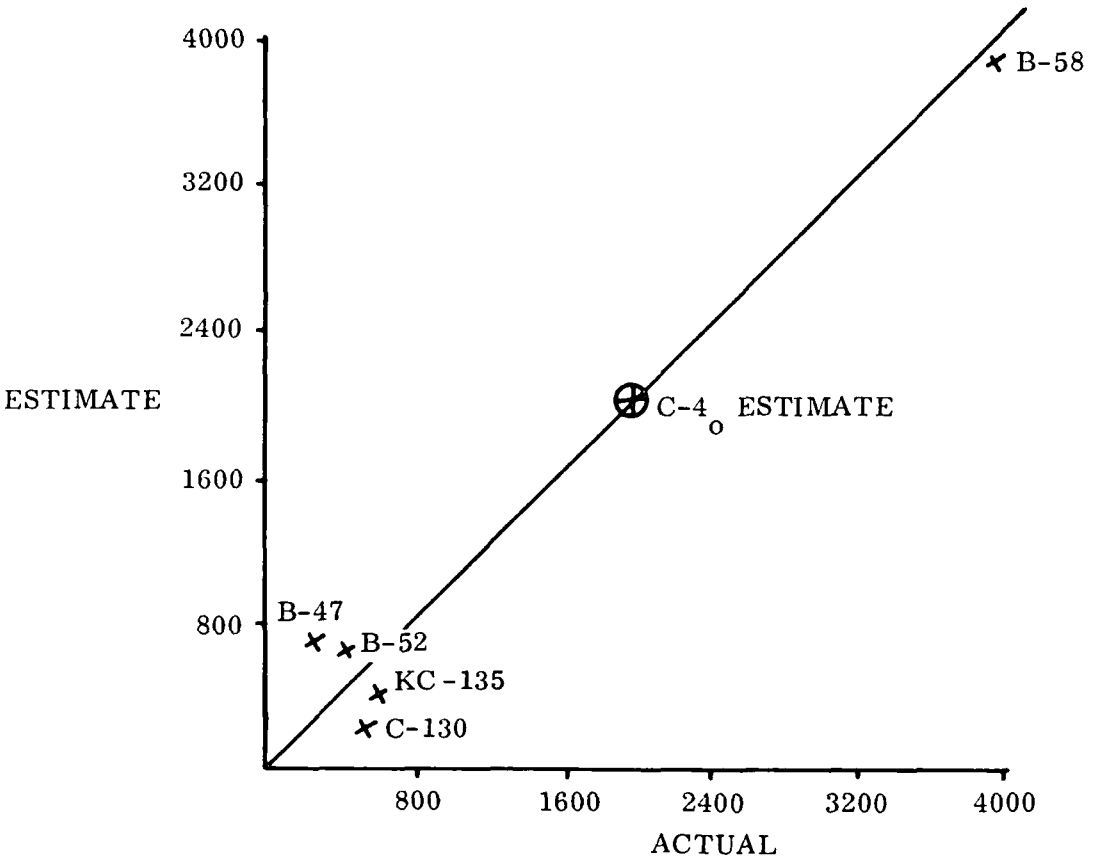


Figure 3.3-9. DDT&E (No Hardware) - $/Lb Comparing Actual vs R-547A Estimated Costs

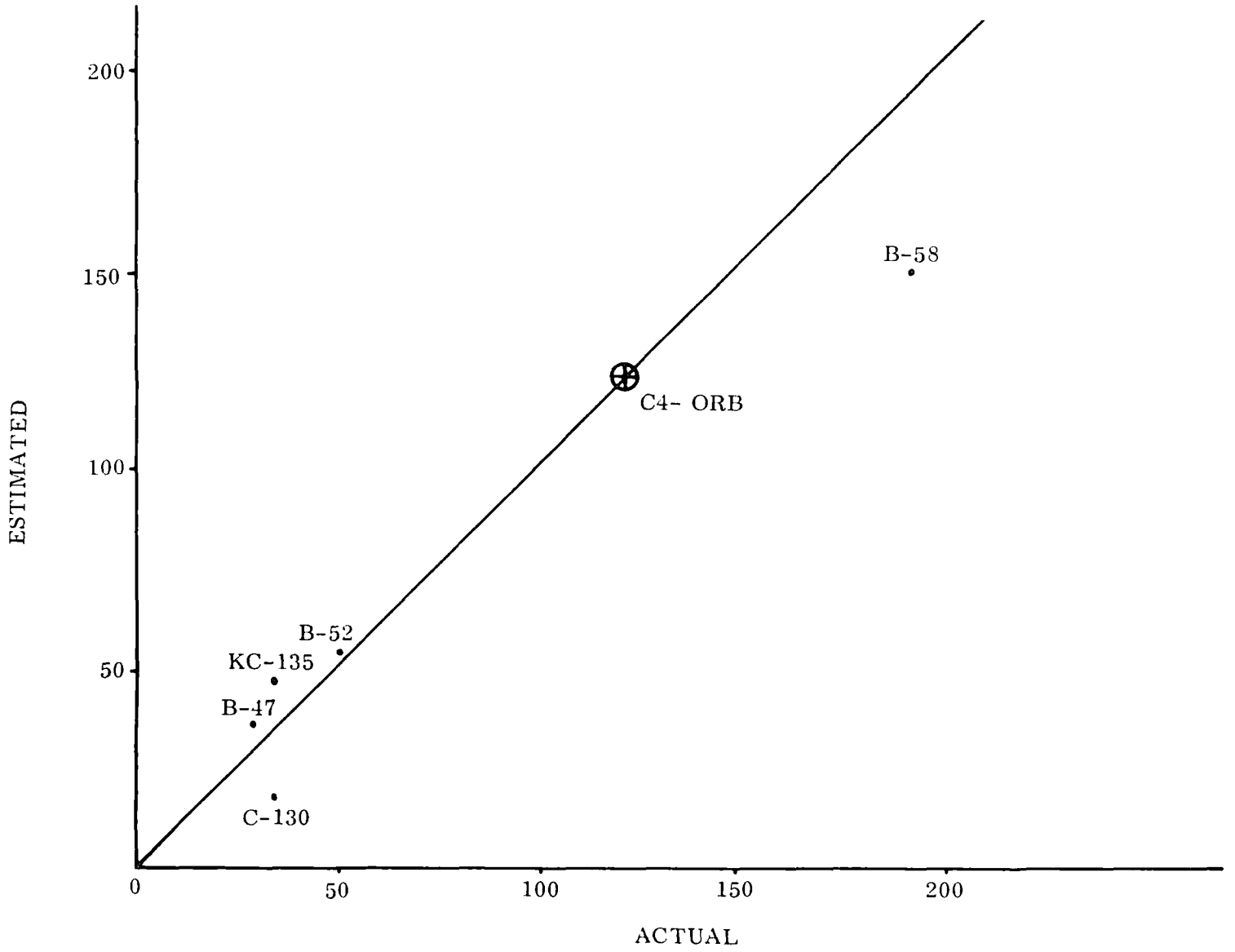


Figure 3.3-10. Recurring Tooling & Engineering $/Lb for A/C #10 Actual vs R-547A Est.

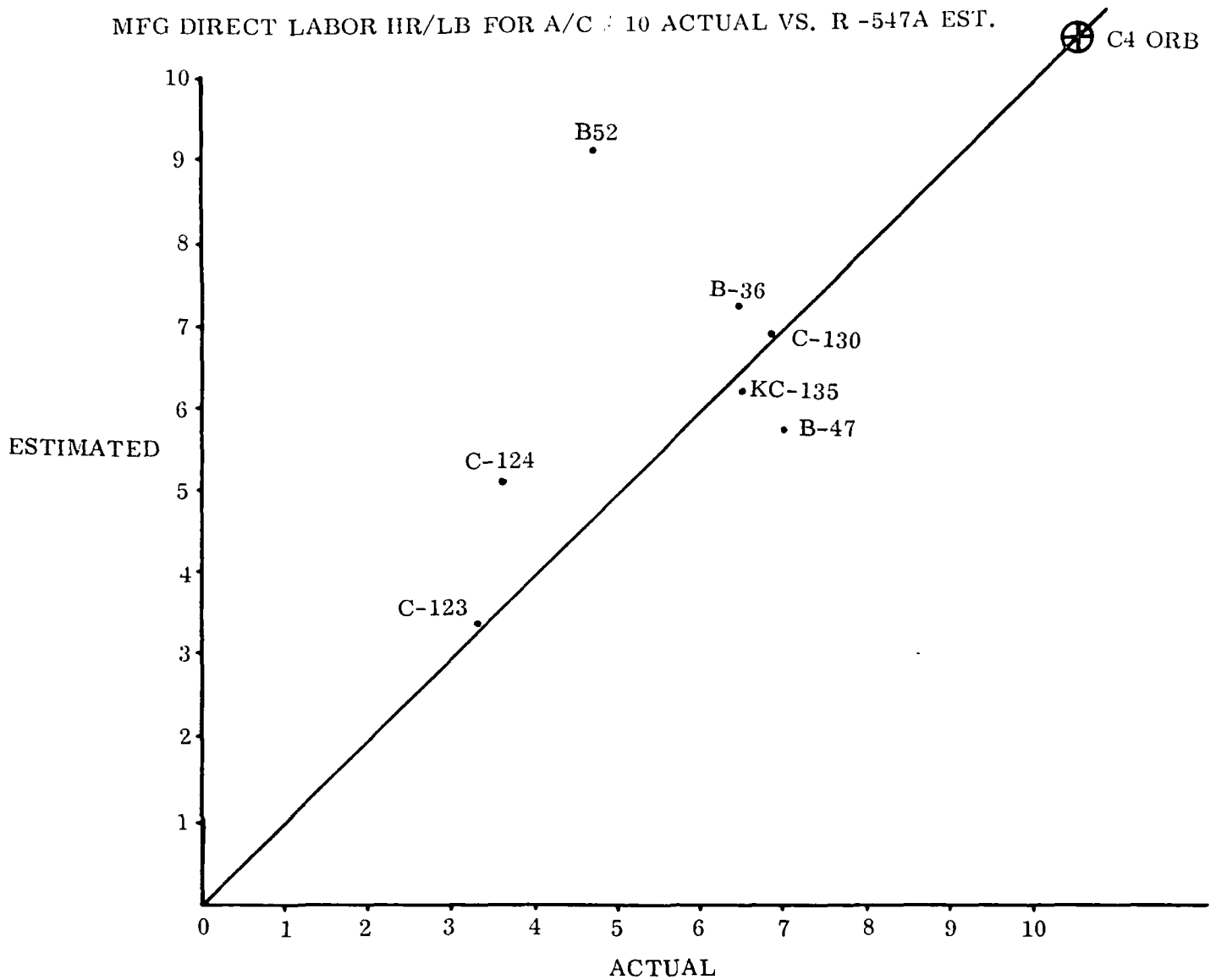


Figure 3.3-11. Mfg Direct Labor Hr/Lb for A/C #10 Actual vs R-547A Est.

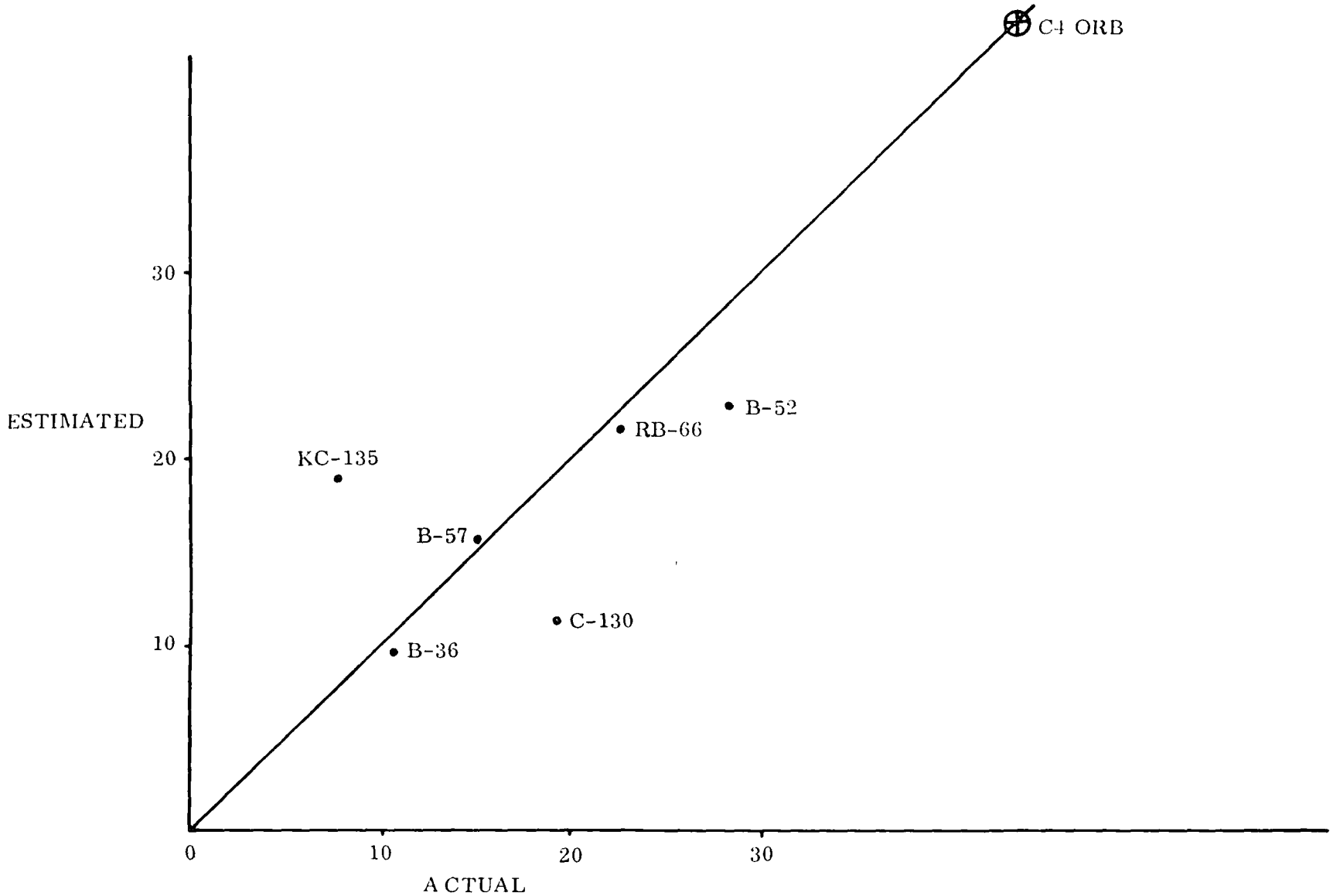


Figure 3.3-12. Mfg Materials $/Lb for A/C #10 Actual vs R-547A Est.

3.4 Test and Operations Cost Estimates

Cost estimates, for implementing Shuttle development and operations, have been derived from the program planning data previously discussed in Volume II Part II. The first part of this subsection covers the cost estimates, and the second part discusses operations cost estimates.

3.4.1 Test Cost Estimate

3.4.1.1 Introduction

Test costs are broken into four categories; Manpower, Test Facilities & GSE, Transportation and Hardware. Costs for system, subsystem, component, material, wind tunnel or related design or development testing is not included here.

Schedules for the major NASA milestones were drawn together from technical decisions and were subsequently costed. A summary of the six-week test program costs and their method of derivation was released as shuttle memo B35-400MO-4. A later test program became the basis for input to total program costing. That test input is summarized in Table 3.4-1. The present schedules for Concepts A, B and C (Section 2.2.2, Figures 2.2-2, -3, -4) were costed and summarized in Table 3.4-2. The next level of detail is provided in Table 3.4-3, -4, which are the basis for numerical examples in the discussion to follow.

3.4.1.2 Manpower

Manpower costs for Ground Test Operations, Horizontal Flight Test Operations, Vertical Launch Test Operations and Base Maintenance & Support include all personnel required to support those tests (flight test, engineering, operations, maintenance, shop, facilities and support) except off-site support which is in DDT&E development engineering costs. The first six-weeks Cost Estimating Relationships (CER's) derived from past programs were applied as block sums for manpower. However, for the three-month report and beyond, each test was man-loaded and an average cost of $1860 per man month was used.

Method: (Applies to Ground Test Ops, Horiz. Ops and Vert. Test Ops.) Test historical data supports an allocation of approximately two-thirds of test span time to build up (requirements definitions, test procedures, etc.) and tail off (analysis, report writing, etc.) See Figure 3.4-1.

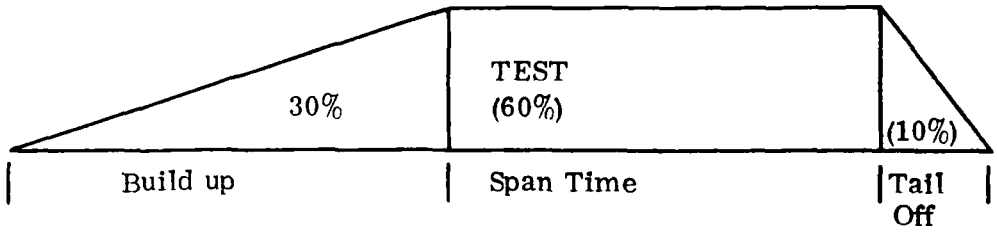


Figure 3.4-1. Test Manpower Distribution

Test span time was manloaded for each type of test (hereafter referred to as 'basic crew') according to data from previous programs and the anticipated shuttle requirements. This basic crew multiplied by a factor of 1.67 and the test span time yielded the total required manmonths.

a) Ground Test Ops. (Table 3.4-3)

C4 Booster Propulsion Static Firing Test Example:

250 men x 19 mos. x 1.67 = 7930 man months

7930 mm x $1860/mo = $14.7 M

b) Horizontal Flight Test Ops. (Table 3.4-3)

'Ground', 'Refurb' and Horiz. schedule blocks are costed as one similar cost.

C4 Orbiter Example:

228 men x 34 Aircraft Months x 1.67 = 13000 man months

13000 mm x $1860/mo = $24.2 M

c) Vertical Flight Test (Table 3.4-3)

1) Vertical Flight Test (Engineers)

C4 Orbiter Example:

126 men x 17 Aircraft Months x 1.67 = 3580 man months

3580 mm x $1860/mo = $6.7 M

2) Vertical Test Ops (operations, maint, etc.)

TABLE 3.4-1. TEST PROGRAM COST SUMMARY

	A1a	A3a	B1a			B1b			B2d			B2i			C4			C4r		
			B	O	B/O	B	O	B/O	B	O	B/O	B	O	B/O	B	O	B/O	B	O	B/O
FACILITIES AND EQUIPMENT																				
• Test Facilities and GSE ($M)	22.6	22.8	-	12.0	10.5	0	12.0	10.5	20.5	12.0	10.5	0	12.0	0	17.5	9.2	12.7	18.5	9.2	12.7
• Trainers and Simulators ($M)	10.0	10.0	-	10.0	-	-	10.0	-	-	10.0	-	-	10.0	-	10.0	10.0	-	10.0	10.0	-
TEST HARDWARE																				
• Ground Test Articles (Units)	1.5	1.5	0	1.5	-	0	1.5	-	1.5	1.5	-	-	1.5	-	1.5	[3] 1.5	-	1.5	[3] 1.5	-
• Flight Test Articles (Units)	3.0	3.0	7.0	3.0	-	8.0	3.0	-	8.0	3.0	-	8.0	3.0	-	2.0	3.0	-	2.0	3.0	-
• Test Article Spares (Units)	0.1	0.1	0.1	0.1	-	0.1	0.1	-	0.1	0.1	-	0.1	0.1	-	0.1	0.1	-	0.1	0.1	-
• Special Test Equipment ($M)	27.0	27.0	8.0	27.0	-	8.0	27.0	-	8.0	27.0	-	8.0	27.0	-	8.0	8.0	15.0	8.0	8.0	15.0
• Expend. Tanks/SRM-Gnd Test (Units)	5/0	3/2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0/2	-	-
• Expend. Tanks/SRM-Flt Test	21/0	14/7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0/14	-	-
• Ferry Kits (Plus Spares)	1.1	1.1	-	1.1	-	-	1.1	-	-	1.1	-	-	1.1	-	-	2.1	-	-	2.1	-
• Dummy Vehicles	-	-	-	1. [1]	-	-	1. [1]	-	-	1. [1]	-	-	1. [1]	-	-	-	-	-	-	-
• Strong Backs-Gnd Test/Flt Test	-	-	1/7	-	-	1/7	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TEST OPERATIONS																				
• Ground Test (Man months)	13590	13590	920	9330	2000	920	9330	2000	11400	9330	2000	-	9330	-	13200	9330	2000	13200	9330	2000
($M)	(25.3)	(25.3)	(1.7)	(17.3)	(3.7)	(1.7)	(17.3)	(3.7)	(21.2)	(17.3)	(3.7)	-	(17.3)	-	(24.6)	(17.3)	(3.7)	(24.6)	(17.3)	(3.7)
• Vertical Launch (Man months)	16315	16315	2600	5880	14000	2600	5880	17300	3040	5880	18400	2380	5880	14000	4250	3720	9950	4250	3720	12200
($M)	(30.4)	(30.4)	(4.8)	(10.9)	(26.0)	(4.8)	(10.9)	(32.2)	(5.6)	(10.9)	(34.2)	(4.4)	(10.9)	(26.0)	(7.9)	(6.9)	(18.5)	(7.9)	(6.9)	(22.7)
• Horizontal Flight (Man months)	12200	12200	-	14500	-	-	14500	-	-	14500	-	-	14500	-	9570	13000	-	9570	13000	-
($M)	(22.7)	(22.7)	-	(27.0)	-	-	(27.0)			(27.0)	-	-	(27.0)	-	(17.8)	(24.2)	-	(17.8)	(24.2)	-
TEST OPERATIONS SUPPORT																				
• Base Maintenance (Man months)	33350	33350	2780	18900	16500	2780	18900	19980	13000	18900	20120	1785	18900	14780	22290	18430	12240	22290	18430	14600
and Support ($M)	(62.0)	(62.0)	(5.2)	(35.2)	(30.7)	(5.2)	(35.2)	(37.1)	(24.2)	(35.2)	(37.6)	(3.3)	(35.2)	(27.4)	(41.5)	(34.3)	(22.8)	(41.5)	(34.3)	(27.2)
TEST HARDWARE CONVERSION				[2]			[2]			[2]			[2]							
• Special Test Instrumentation/ Hardware Refurbishment ($M)	30.0	30.0	-	30.0	-	-	30.0	-	-	30.0	-	-	30.0	-	20.0	20.0	-	20.0	20.0	-

[1] Costed as 20% Orbiter value
[2] This figure was included in 'vert. launch' total submitted to TBC Cost personnel
[3] The third orbiter was included in time for computer input. All orbiter associated costs will be added as soon as possible.

TABLE 3.4-2. TEST PROGRAM COST SUMMARY

	A1a	A3a	B1a			B1b			B2d			B2i			C4			C4r		
			B	O	B/O	B	O	B/O	B	O	B/O	B	O	B/O	B	O	B/O	B	O	B/O
FACILITIES AND EQUIPMENT																				
• Test Facilities & GSE ($M)	22.6	22.8	-	12.0	10.5	-	12.0	10.5	20.5	12.0	10.5	-	12.0	-	17.5	9.2	13.2	18.5	9.2	13.2
• Trainers & Simulators ($M)	10.0	10.0	-	10.0	-	-	10.0	-	-	10.0	-	-	10.0	-	10.0	10.0	-	10.0	10.0	-
TEST HARDWARE																				
• Ground Test Articles (Units)	1.5	1.5	0	1.5	-	0	1.5	-	1.5	1.5	-	--	1.5	-	1.5	1.5	-	1.5	1.5	-
• Flight Test Articles (Units)	3.0	3.0	7.0	3.0	-	7.0	3.0	-	8.0	3.0	-	8.0	3.0	-	2.0	2.0	-	2.0	2.0	-
• Test Article Spares (Units)	0.1	0.1	0.1	0.1	-	0.1	0.1	-	0.1	0.1	-	0.1	0.1	-	0.1	0.1	-	0.1	0.1	-
• Special Test Equipment ($M)	27.0	27.0	7.0	27.0	-	7.0	27.0	-	8.0	27.0	-	8.0	27.0	-	8.0	8.0	15.0	8.0	8.0	15.0
• Expend. Tanks/SRM-Gnd Test (Units)	5/0	3/2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	- -	0/2	-	-
• Expend. Tanks/SRM/Flt Test (Units)	21/0	14/7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0/14	-	-
• Ferry Kits (Plus Spares)	1.1	1.1	-	1.1	-	-	1.1	-	-	1.1	-	-	1.1	-	-	2.1	-	-	2.1	-
• Dummy Vehicles (Units)	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	-
• Strong Backs - Gnd Test/Flt Test	-	-	1/7	-	-	1/7	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TEST OPERATIONS																				
• Ground Test (Man months)	15030	15030	920	10740	2000	920	10740	2000	14870	10740	2000	-	10740	-	14880	10740	2000	14880	10740	2000
($M)	(28.0)	(28.0)	(1.7)	(20.0)	(3.7)	(1.7)	(20.0)	(3.7)	(27.6)	(20.0)	(3.7)	-	(20.0)	-	(27.6)	(20.0)	(3.7)	(27.6)	(20.0)	(3.7)
• Horizontal Flight (Man months)	14500	14500	-	14500	-	-	14500	-	-	14500	-	-	14500	-	11100	13000	-	11100	13000	-
($M)	(27.0)	(27.0)	-	(27.0)	-	-	(27.0)	-	-	(27.0)	-	-	(27.0)	-	(20.6)	(24.2)	-	(20.6)	(24.2)	-
• Vertical Launch (Man months)	14200	14140	4120	6520	11100	4120	6520	13700	5210	6520	17000	5210	6520	12600	4250	3580	9050	4250	3580	11250
($M)	(26.4)	(26.3)	(7.7)	(12.1)	(20.6)	(7.7)	(12.1)	(25.5)	(9.7)	(12.1)	(31.6)	(9.7)	(12.1)	(23.4)	(7.9)	(6.7)	(16.8)	(7.9)	(6.7)	(20.9)
TEST OPERATIONS SUPPORT																				
• Base Maintenance (Man months)	32065	32065	3555	20470	13400	3555	20470	16200	17040	20470	19650	3700	20470	13200	24070	17810	11300	24070	17810	13600
& Support ($M)	(59.7)	(59.7)	(6.6)	(38.1)	(24.9)	(6.6)	(38.1)	(30.1)	(31.7)	(38.1)	(36.5)	(6.9)	(38.1)	(24.6)	(44.8)	(33.1)	(21.0)	(44.8)	(33.1)	(25.3)
TEST HARDWARE CONVERSION																				
• Special Test Instrumentation Hardware Refurbishment ($M)	30.0	30.0	-	30.0	-	-	30.0	-	-	30.0	-	-	30.0	-	20.0	20.0	-	20.0	20.0	-

1 Cost as 20% Orbiter Value

TABLE 3.4-3. TEST OPS SUMMARY

	A1a			A3a			B1a			B1b			B2d			B2i			C4			C4r		
	Tanks	Orb	Comb	Tanks	Orb	Comb	B	O	B/O	B	O	B/O	B	O	B/O	B	O	B/O	B	O	B/O	B	O	B/O
GROUND TEST																								
Static Struct Test																								
Basic Crew (men)	50	185	-	50	185	-	110	185	-	110	185	-	162	185	-	-	185	-	208	185	-	208	185	-
Test Span Time (mos)	9	20	-	9	20	-	5	20	-	5	20	-	14	20	-	-	20	-	20	20	-	20	20	-
Total Ops (mm)	750	6180	-	750	6180	-	920	6180	-	3770	6180	-	3770	6180	-	-	6180	-	6950	6180	-	6950	6180	-
Dynamic Struct Test																								
Basic Crew (men)	-	-	200	-	-	200	-	-	200	-	-	200	-	-	200	-	-	-	-	-	200	-	-	200
Test Span Time (mos)	-	-	6	-	-	6	-	-	6	-	-	6	-	-	6	-	-	-	-	-	6	-	-	6
Total Ops (mm)	-	-	2000	-	-	2000	-	-	2000	-	-	2000	-	-	2000	-	-	-	-	-	2000	-	-	2000
Propulsion Static Firing Test																								
Basic Crew (men)	-	-	215	-	-	215	-	210	-	-	210	-	510	210	-	-	210	-	250	210	-	250	210	-
Test Span Time (mos)	-	-	17	-	-	17	-	13	-	-	13	-	13	13	-	-	13	-	19	13	-	19	13	-
Total Ops (mm)	-	-	6100	-	-	6100	-	4560	-	-	4560	-	11100	4560	-	-	4560	-	7930	4560	-	7930	4560	-
Gnd Test Subtotal (mm)	750	6180	8100	750	6180	8100	920	10740	2000	920	10740	2000	14870	10740	2000	-	10740	-	14880	10740	2000	14880	10740	2000
($M)	(1.4)	(11.5)	(15.1)	(1.4)	(11.5)	(15.1)	(1.7)	(20.0)	(3.7)	(1.7)	(20.0)	(3.7)	(27.6)	(20.0)	(3.7)		(20.0)		(27.6)	(20.0)	(3.7)	(27.6)	(20.0)	(3.7)
HORIZONTAL FLIGHT TEST																								
Basic Crew (men)	-	228	-	-	228	-	-	228	-	-	228	-	-	228	-	-	228	-	185	228	-	185	228	-
Test Span Time (A/C mos)	-	38	-	-	38	-	-	38	-	-	38	-	-	38	-	-	38	-	36	34	-	36	34	-
Total Ops (mm)	-	14500	-	-	14500	-	-	14500	-	-	14500	-	-	14500	-	-	14500	-	11100	13000	-	11100	13000	-
($M)	-	(27.0)	-	-	(27.0)	-	-	(27.0)	-	-	(27.0)	-	-	(27.0)	-	-	(27.0)	-	(20.6)	(24.2)	-	(20.6)	(24.2)	-
VERTICAL FLIGHT TEST																								
Vertical Flight Test																								
Basic Crew (men)	-	-	126	-	-	126	130	126	-	130	126	-	130	126	-	130	126	-	130	126	-	130	126	-
Test Span Time (A/C mos)	-	-	30	-	-	30	19	31	-	19	31	-	24	31	-	24	31	-	20	17	-	20	17	-
Total Ops (mm)	-	-	6300	-	-	6300	4120	6520	-	4120	6520	-	5210	6520	-	5210	6520	-	4340	3580	-	4340	3580	-
Vertical Test Ops																								
Basic Crew (men)X Span Time (502X11) +Basic Crew(men)X Span Time				(498X11)			(210X14)+ (400X12)			(252X14)+ (506X12)			(358X19)+ (408X12)			(216X19)+ (392X12)			(330X15)+ (198X7)			(432X15)+ (198X7)		
Total Ops (mm)	-	-	7900	-	-	7840	-	-	11100	-	-	13700	-	-	17000	-	-	12600	-	-	9050	-	-	11250
Vertical Flt Test Subtotal (mm)	-	-	14200	-	-	14140	4120	6520	11100	4120	6520	13700	5210	6520	17000	5210	6520	12600	4340	3580	9050	4340	3580	11250
($M)	-	-	(26.4)	-	-	(26.3)	(7.7)	(12.1)	(20.6)	(7.7)	(12.1)	(25.5)	(9.7)	(12.1)	(31.6)	(9.7)	(12.1)	(23.4)	(8.1)	(6.7)	(16.8)	(8.1)	(6.7)	(20.9)

TABLE 3.4-4. BASE MAINTENANCE & SUPPORT SUMMARY

GROUND TEST	A1a			A3a			B1a			B1b			B2d			B2i			1 C4			C4r		
STATIC STRUCT. TEST	tanks	orb	comb	tanks	orb	comb	B	O	B/O	B	O	B/O	B	O	B/O	B	O	B/O	B	O	B/O	B	O	B/O
Basic Crew (Men)	50	185	-	50	185	-	110	185	-	110	185	-	162	185	-	-	185	-	208	185	-	208	185	-
Pre-FMOF Span Time (MOS)	9	20	-	9	20	-	5	20	-	5	20	-	14	20	-	-	20	-	20	20	-	20	20	-
Total (MM)	675	5550	-	675	5550	-	825	5550	-	825	5550	-	3400	5550	-	-	5550	-	6250	5550	-	6250	5550	-
DYNAMIC STRUCT. TEST																								
Basic Crew (Men)	-	-	200	-	-	200	-	-	200	-	-	200	-	-	200	-	-	-	-	-	200	-	-	200
Pre-FMOF Span Time (MOS)	-	-	6	-	-	6	-	-	6	-	-	6	-	-	6	-	-	-	-	-	6	-	-	6
Total (MM)	-	-	1800	-	-	1800	-	-	1800	-	-	1800	-	-	1800	-	-	-	-	-	1800	-	-	1800
PROPULSION STATIC FIRING TEST																								
Basic Crew (Men)	-	-	215	-	-	215	-	210	-	-	210	-	510	210	-	-	210	-	250	210	-	250	210	-
Pre-FMOF Span Time (MOS)	-	-	17	-	-	17	-	13	-	-	13	-	13	13	-	-	13	-	19	13	-	19	13	-
Total (MM)	-	-	5480	-	-	5480	-	4100	-	-	4100	-	9940	4100	-	-	4100	-	7130	4100	-	7130	4100	-
GROUND TEST SUBTOTAL (MM)	675	5550	7280	675	5550	7280	825	9650	1800	825	9650	1800	13340	9650	1800	-	9650	-	13380	9650	1800	13380	9650	1800
($M)	1.3	10.3	13.5	1.3	10.3	13.5	1.5	17.9	3.3	1.5	17.9	3.3	24.8	17.9	3.3	-	17.9	-	24.9	17.9	3.3	24.9	17.9	3.3
HORIZONTAL FLIGHT TEST																								
Basic Crew (Men)	-	228	-	-	228	-	-	228	-	-	228	-	-	228	-	-	228	-	185	228	-	185	228	-
Pre-FMOF Span Time (MOS)	-	24	-	-	24	-	-	25	-	-	25	-	-	25	-	-	25	-	-28	25	-	28	20	-
Total (MM)	-	8200	-	-	8200	-	-	8550	-	-	8550	-	-	8550	-	-	8550	-	7770	6840	-	7770	6840	-
VERTICAL FLIGHT TEST																								
VERTICAL FLIGHT TEST																								
Basic Crew (Men)	-	-	126	-	-	126	130	126	-	130	126	-	130	126	-	130	126	-	130	126	-	130	126	-
Pre-FMOF Span Time (MOS)	-	-	11	-	-	11	14	12	-	14	12	-	19	12	-	19	12	-	15	7	-	15	7	-
Total (MM)	-	-	2080	-	-	2080	2730	2270	-	2730	2270	-	3700	2270	-	3700	2270	-	2920	1320	-	2920	1320	-
VERTICAL TEST OPS																								
Basic Crew X pre-FMOF Span Time + Basic Crew X pre-FMOF Span Time		(502X11)			(498X11)			(210X14)+ (400X12)			(252X14)+ (506X12)			(358X19)+ (408X12)			(216X19)+ (392X12)			(330X15)+ (198X7)			(432X15)+ (198X7)	
Total (MM)	-	-	8280	-	-	8210			11600			14400			17850			13200			9500			11800
VERTICAL FLIGHT TEST SUBTOTAL (MM)	-	-	10360	-	-	10360	2730	2270	11600	2730	2270	14400	3700	2270	17850	3700	2270	13200	2920	1320	9500	2920	1320	11800
($M)			19.3			19.3	5.1	4.2	21.6	5.1	4.2	26.8	6.9	4.2	33.2	6.9	4.2	24.6	5.4	2.5	17.7	5.4	2.5	22.0
TOTAL (MM)	675	13750	17640	675	13750	17640	3555	20470	13400	3555	20470	16200	17040	20470	19650	3700	20470	13200	24070	17810	11300	24070	17810	13600
($M)	1.3	25.6	32.8	1.3	25.6	32.8	6.6	38.1	24.9	6.6	38.1	30.1	31.7	38.1	36.5	6.9	38.1	24.6	44.8	33.1	21.0	44.8	33.1	25.3

A build-up rate for operations and maintenance was assumed which yielded a factor of 1.43. Costs were obtained by multiplying this factor by the basic crew and span time (through FMOF). After FMOF these people are included in 'Operations' costs.

C4 Example:

From the Operations Analysis sheets there are three manpower figures for C4:

1) 86 men for orbiter only functions; 2) 82 men for booster only functions; 3) 96 men for combined functions. This is the single flow manpower required for the 100th operational launch (5th year). A 90% learning curve brought back to the first launch necessitates a doubling of these figures, and all test launches through FMOF were costed at this rate.

To launch boosters only we would need:

$$2\ [82 + (96-13)]\ \text{men} = 2\ (165) = \underline{330\ \text{men}}$$

(13 men are used for mating boosters and orbiters)

To make mated launches we would additionally need:

$$2\ [86 + 13]\ = 2\ (99) = \underline{198\ \text{men}}$$

There are 15 months that boosters will be launched (including Prelaunch) and 7 months for mated launch operations. Therefore,

$$330\ \text{men} \times 15\ \text{mos} \times 1.43 = 7070\ \text{man months}$$

$$198\ \text{men} \times 7\ \text{mos} \times 1.43 = \underline{1980\ \text{man months}}$$

$$9050\ \text{man months}$$

$$9050\ \text{mm} \times \$1860/\text{mo} = \underline{\$16.8\text{M}}$$

d) Base Maintenance and Support (Table 3.4-4)

A factor of 1.5 was multiplied by the basic crew and the test span time, and was used for all tests. When the Horizontal and Vertical tests go beyond FMOF, base maintenance and support is costed in 'Operations to avoid double costing.

C4 Booster Vert. Flt. Test Example:

130 men x 15 pre-FMOF mos x 1.5 = 2920 man months

2920 mm x $1860/mo = $4.4M

3.4.1.3 Test Facilities and Equipment

Test facilities and Ground Support Equipment (GSE) are those facilities and GSE required to support the test program but having no function in the operations program. (Those facilities and GSE which are required by the test program and the operational program are costed separately in the operations cost analysis.)

Test facilities and GSE which were costed include the following:

a) Ground static structural test facility.

b) Ground dynamic test facility.

c) Ground static firing test facility.

Other facilities peculiar to the test program such as horizontal test site maintenance hangar, airport and office buildings are assumed available in the appropriate time period.

A trade study was conducted to determine the cost difference between modifying existing facilities and building new facilities at KSC. These data are summarized for reference.

a) Ground static structural test facility.

The size building required to accommodate the test article was determined and cost calculated with an allowance for extra floor strengthening to accept the testing fittings. The calculation for the C4 booster is shown.

length bay	width bay	square feet	st'd. bay cost	floor strengthening ($10/ft.^{2})	total building cost
315 ft	271 ft	85,400	$5.6M	$0.9M	$6.5M

The requirement for applying heat to the test article during the static structural test was costed on the following basis for the C4 booster.

material	stable temperature required	estimated area	radiant heat power required	Approx total power required
aluminum	250°F	3000 ft^2	5 kw/ft^2	15 megawatts
titanium	600°F	1500 ft^2	10 kw/ft^2	15 megawatts

Control equipment was determined to be:

SCR AC Power controllers		$10/KW =	$300,000
Control Equipment		$1000/500KW =	60,000
Test Computer Control		$100,000	100,000
Lamps/Deflectors	($80/$ft^2$ for 250°) ($120/$ft^2$ for 600°)		420,000
			$880,000

Electrical Service Equipment was determined to be:

Line to substation	$20,000
Primary substation	100,000
Secondary substation	500,000
Distribution	100,000
	$720,000

Total radiant heating system cost is:

Control Equipment	$880,000
Electrical Service	720,000
Electric Bill (350 hr)	100,000
Total heating system costs =	$1,700,000

It was assumed that an air conditioning system was required to prevent over-temperature of the area during sustained testing. The system was not sized for human comfort but to prevent excessive ambient temperatures in the area around the static test. A cost of $2.0M was indicated based upon an installed price of $950 per ton to remove 25% of the radiant heat.

b) Ground Dynamic Test Facility

The existing Huntsville dynamic test facility was used to shake the Sat V stack and would have to be extensively modified to accommodate the candidate mated C4 shuttle. Lack of detailed shuttle test requirements and configuration definition preclude making a detailed estimate of the nature of the changes so it was assumed that 30% rework will be required. The initial cost of the facility (in 1965 dollars) was $21.2 million so $10 million is used for rework which allows about 30% for inflation of building costs.

During the course of the study it became desirable to determine the cost penalty of performing a ground dynamic test at places other than Huntsville if a manufacturing and transportation trade study showed it to be desirable. It turned out that the cost of the new facility far exceeded transportation costs so the Huntsville facility still appeared attractive, but the numbers are presented below for reference.

Alternate Ground Dyanmic Test Facilities ($\$x10^6$)

			MTF		KSC	
	1965 Huntsville	1970 Huntsville	100% New	Max Use Of Exist. Equip.	100% New	Max Use Of Exist. Equip.
Foundation, Strucures and Utilities	5.5M	7.1	7.1	7.1	9.1	9.1
Instrumentation and Data System	5.5	7.1	7.1	3.0	7.9	3.0
GSE Including Shaker Pots and Support System	10.2	13.2	13.2	5.0	15.2	5.0
TOTAL COST	21.2	27.4	27.4	15.1	32.2	17.1

c) Propulsion Test Facility

The existing MSFC and MTF static firing test stands are assumed available to support the shuttle program and modification costs are estimated at $10.0M for the Booster stages and $5.0M for the Orbiter. A trade study was conducted to consider the possibility of using alternate propulsion test facilities at KSC and is presented for reference in the following graph (Figure 3.4-2) which is based upon original S1 and S2 test stand costs updated from 1964 dollars and delta costs associated with KSC labor and material cost differentials. The booster thrust of 4,600,000 pounds would require a new test stand costing about $90M.

3.4.1.4 Transportation

The ground dyanmic test requires barge transportation of the shuttle between the manufacturing and test site and assembly at the remote site. An allowance of $0.5M is included.

3.4.1.5 Test Hardware

a) Trainers & Simulators

The LM Mission Simulator (LMS) was used as the basis for trade study to determine if modifications to existing equipment would be more cost-effective than a new purchase. When a 6% inflation rate is assumed, a 1970 LMS cost would be approximately $23M. The LMS modifications that would be required are:

- New cabin
- Mission Effects Projection
- Ascent and landing equipment
- Rendezvous and docking
- Software
- Malfunctions
- Instructor's station
- Interface equipment
- Controlling equipment racks

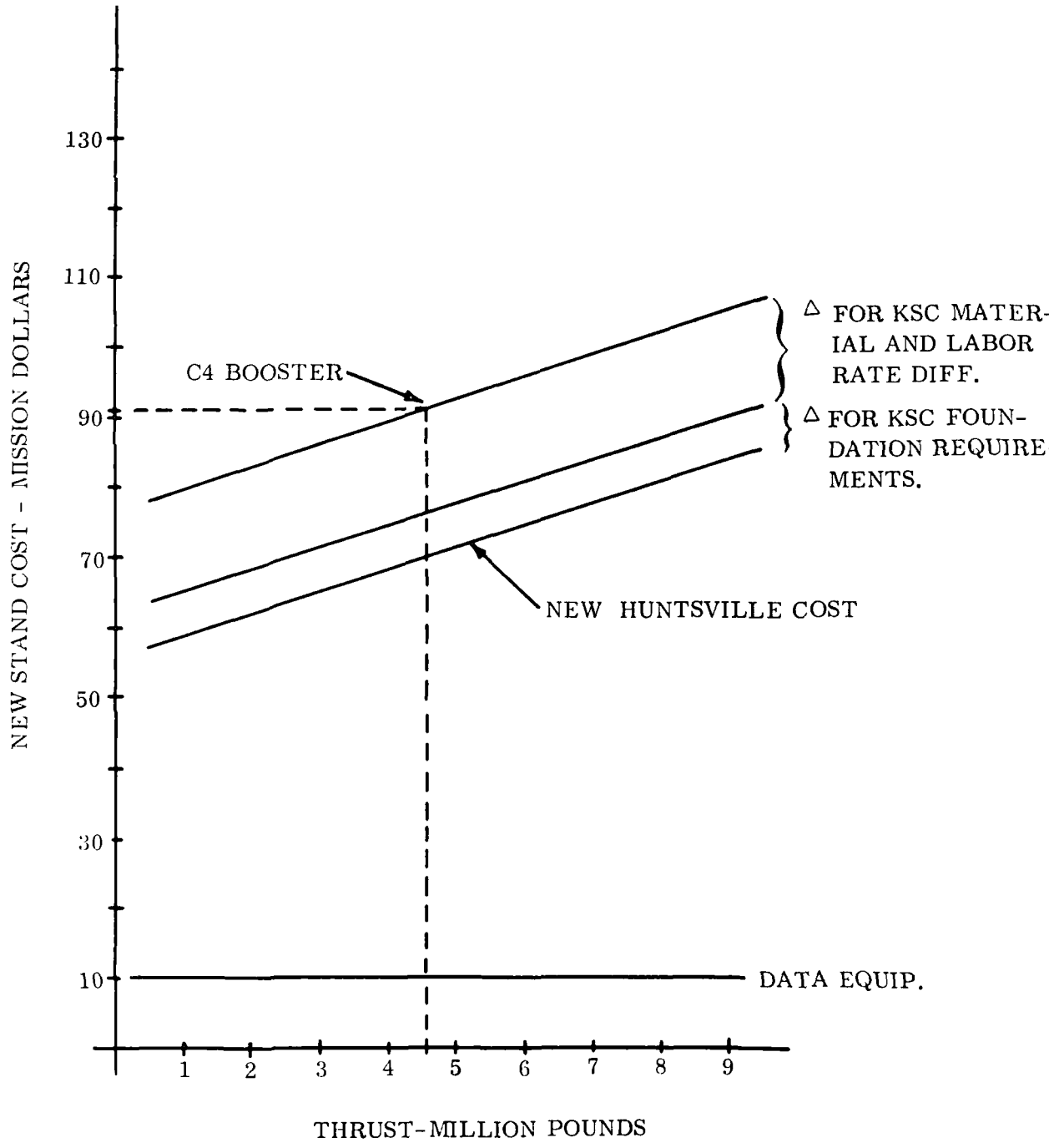


Figure 3.4-2. Propulsion Test Stand Cost Estimate

Costs were estimated as follows:

Hardware and software	$ 6.5M
Administration and Integration:	
40 men X 30 mos. X $1860/mo	2.2M
Operations:	
20 men X 36 mos X $1860/mo	1.3M
Total	$10.0M

One modified LMS would be required for the orbiter program, and another for the reusable booster program.

b) Special Test Equipment

Concept 'A' - airborne flight test instrumentation = 4.0M/Core Veh.
- ground equip. to support flight test = 15 M

3 veh. X 4 M/veh + 15 M = $27 M

Concept 'B' - Airborne flight test instr. = 4.0M/Orbiter
Airborne flight test instr. = 1.0M/Booster

ground equip. to support flight test = 15 M

3 orb X 4M/orb + 15M + 7 boost X 1.0M/boost = $34M

(B2d and B2i each have 8 boosters)

Concept 'C' - Airborne flight test instr. - 4.0M/Orbiter
Airborne flight test instr. = 4.0M/booster
ground equip. to support flight test = 15M

2 orb X 4M/orb + 2 boost X 4M/boost + 15M = $31M

Airborne flight test instrumentation costs were derived from TBC commercial transport data with a factor added to allow for expected increased complexity due to TPS and cryo tankage instrumentation. "B" booster costs were from S1C data.

Ground equipment costs were based on the GAC F-14 Automatic Telemetry Station costs. It may be revised downward when the results of a study of available

ground data systems is completed. These costs are based upon current acquisition of a real time data facility capable of tracking and receiving 1500 channels (on 3 independent simultaneous test vehicles) at a max word rate of 50,000 per second. Costs are:

Facilities	$1.5M
Data System	11.5M
Software	2.0M
Total	$15.0M

c) Test Articles

The number of ground test articles and flight test articles is indicated in the Test Article Cost Summary in terms of equivalent units. Each flight test unit is costed as a complete operational vehicle to obtain the DDT&E program costs of which this study is part. The static structural ground test article is considered to be structurally complete but devoid of systems and, after coordination with manufacturing and finance people, is estimated to cost 75% of a complete vehicle. The propulsion test vehicle is considered to be a complete flight weight article insofar as the main propulsion tanks, fluid and control systems are concerned but does not have wings (except as required to mount the ACPS), tail, landing gear, flight controls and crew cabin. It is similarly considered to cost 75% of a complete vehicle price. The requirement for mass balance, aerodynamic similarity and guidance and control during the unmanned flightrating launch of the expendable boosters is intended to be fulfilled by a dummy orbiter estimated to cost 20% of a production orbiter.

The remaining hardware (tanks, SRM's and strongbacks) are merely those articles required to support the test program and are determined by the number of dedicated ground test units and expended flight test units required.

d) Flight Test Vehicle Conversion

Large commercial transports have been converted from test use to operational use at an average cost of $3.3M. This was increased by consideration of difficulty in removing cryo and TPS test instrumentation, higher number of sensors and thorough checkout upon completion. We used $10M per vehicle.

3.4.2 Operations Costs Estimates

3.4.2.1 Manpower Costing

To arrive at yearly manpower costing, the various functions and activities were plotted against time and single flow capability for these functions was established; from the traffic model, unit demand requirements were defined on a yearly basis and functions were staffed to support this requirement. Tables 3.4-5 thru -7 give the equivalent dollar costs based on $22,320.00 per man year. A 90% learning curve was used on all functions which were felt would respond to the "learning curve" technique.

The figures listed above show yearly costs and total costs for three configurations. Table 3.4-8 shows total operations manpower costs at varying traffic rates for all concepts.

After determining the total direct manpower requirements, a 2 to 1 factor was applied for base maintenance and support. The following breakdown indicates tasks performed within this category:

- Security and Fire Protection
- Maintenance of grounds and buildings
- Food service
- Photographic and reproduction service
- Computer service
- Medical service
- Consumable delivery
- Spares warehousing
- Support shops and labs (including LRU repair)
- Base administration and protocol GSA

TABLE 3.4-5. CONCEPT A3 MANDOLLARS/YR. 445 FLIGHTS

	1	2	3	4	5	6	7	8	9	10	10 Year Total 445 Flt.
• Launch & Rec Ops											
1.0 Recvng Ops	223.2	←	←	←	223.2	334.8	←	←	←	334.8	
3.0 Payload Inst.	223.2	200.9	156.2	133.9	←	←	←	←	←	133.9	
4.0 Prep for flt.	1495.4	1272.2	1116.0	1026.7	937.4	937.4	1874.9	←	←	1874.9	
5.0 Pre Flt. Ops	1651.7	1383.8	1227.6	1138.3	1026.7	←	←	←	←	1026.7	
11.0 Pad Recycle	401.8	←	←	←	←	←	←	←	←	401.8	
Sub Tot	4394.8	3830.1	3437.3	3216.3	2995.3	3118.1	4149.3	4149.3	←	4149.3	37589.1
• Flight Ops											
9.0 Mission Supp.	883.9	←	←	←	←	←	←	←	←	883.9	8839.0
Maintenance & c/o											
Orbiter Only											
2.0 M R & c/o	3142.7	2651.7	2357.0	4321.1	3928.3	3928.3	5892.5	←	←	5892.5	43899.1
Booster Only											
2.0 M R & c/o	1399.4	1571.4	2136.0	2258.7	2946.2	3535.5	3830.1	5008.6	←	5008.6	32703.1
Total Direct	9820.8	8937.1	8814.2	10680.0	10753.7	11465.8	14755.8	15934.3	←	15934.3	123030.3
• Base Support											
200% Direct	19641.6	17874.2	17,628.4	21360.0	21507.4	22931.6	29511.6	31868.6	←	31868.6	246060.6
Total Direct +B. S.	29462.4	26811.3	26442.6	32040.0	32261.1	34397.4	44267.4	47802.9	←	47802.9	369090.9

Dollars x 10^3

TABLE 3.4-6. CONCEPT Bla MANDOLLARS/YR. 445 FLIGHTS

YEAR	1	2	3	4	5	6	7	8	9	10	10 Year Total
• Launch & Rec Ops											
1.0 Recvng Ops	223.2				223.2	334.8				334.8	
3.0 Payload Inst.	223.2	200.9	156.2	133.9						133.9	
4.0 Prep for Flt.	1138.3	959.8	870.5	781.2	714.2					714.2	
5.0 Pre Flt Ops	2142.7	1807.9	1607.0	1495.4	1361.5	1361.5		1741.0		1741.0	
11.0 Pad Recycle	446.4									446.4	
Sub Total	4173.8	3638.2	3303.3	3080.1	2879.2	2990.8	3370.3	3370.3		3370.3	33167.1
• Flight Ops											
9.0 Mission Supp.	883.9									883.9	8839.0
• Maintenance & c/o											
Orbiter Only											
2.0 M R & c/o	2499.8	2120.4	1874.9	3437.3	3124.8	3124.8	3124.8	4687.2	4687.2	4687.2	33368.4
10% Eng.	250.0	212.0	187.5	343.7	312.5	312.5	312.5	468.7	468.7	468.7	3336.8
Sub Tot.	2749.8	2332.4	2062.4	3781.0	3437.3	3437.3	3437.3	5155.9	5155.9	5155.9	36705.2
Booster Only											
2.0 M R & c/o	7588.8	6383.5	8258.4	9977.0	11227.0	13369.7	17856.0	19864.8		19864.8	134254.8
Total Direct	15396.3	13238.0	14508.0	17722.0	18427.4	20681.7	25168.0	29274.9		29274.9	212966.1
• Base Support											
200% Direct	30792.6	26476.0	29016.0	35444.0	36854.8	41363.4	50336.0	58549.8		58549.8	425932.2
Total Direct +B.S.	46188.9	39714.0	43524.0	53166.0	55282.0	62045.1	75504.0	87824.7		87824.7	638898.3

Dollars x 10^3

TABLE 3.4-7. CONCEPT C-4 MANDOLLARS/YR. 445 FLIGHTS

Year	1	2	3	4	5	6	7	8	9	10	10 Year Total 445 flt
• Launch & Rec Ops											
1.0 Recvng Ops	223.2	←	←	←	223.2	334.8	←	←	←	334.8	
3.0 Payload Inst.	223.2	200.9	156.2	133.9	←	←	←	←	←	133.9	
4.0 Prep for flt.	1004.4	848.2	758.9	691.9	625.0	625.0	625.0	1249.9	1249.9	1249.9	
5.0 Pre Flt Ops	1718.6	1450.8	1294.6	1183.0	1071.4	←	←	←	←	1071.4	
11.0 Pad Recycle	178.6	←	←	←	178.6	267.8	←	←	←	267.8	
Sub Total	3682.3	3191.9	2822.7	2651.7	2455.3	2676.2	2676.2	3363.6	←	3363.6	30297.6
• Flight Ops											
9.0 Mission Supp.	883.9	←	←	←	←	←	←	←	←	883.9	8839.0
• Maintenance & c/o											
Orbiter Only											
2.0 MR & c/o	2749.8	2332.4	2062.4	3781.0	3437.3	3437.3	3437.3	5155.9	←	5155.9	36705.2
Booster Only											
2.0 MR & c/o	2946.2	2479.7	2037.9	4002.0	3633.7	3633.7	5450.5	←	←	5450.5	40535.2
Total Direct	10262.7	8887.9	7856.9	11318.6	10410.2	10631.1	12447.9	14853.9	14853.9	14853.9	116377.0
• Base Support											
200% Direct	20525.4	17775.8	15713.8	22637.2	20820.4	21262.2	24895.8	29707.4	←	29707.8	232754.0
Total Direct +B.S.	30788.1	26663.7	23570.7	33955.8	31230.6	31893.3	37343.7	44561.7	←	44561.7	349131.0

Dollars x 10^3

TABLE 3.4-8. TOTAL OPERATIONS MANPOWER COSTS - 10 YEARS VARYING TRAFFIC DOLLARS x 10^3

Total No. of Flights	A1	A3a	B1a	B2d	B2i	C4
100	222147.9	220897.8	340223.7	460684.8	254558.9	228553.8
220	247931.1	248149.2	393657.8	556303.7	319064.4	222011.5
365	319787.1	317163.0	549540.6	802515.6	397072.8	302362.9
445	362905.2	369090.9	638898.3	954514.8	458475.1	349131.0

3.4.2.2 Operations Facilities Costs

Operation facility costs to support a launch rate of 75 per year are identified in Table 3.4-9. Summary Operation Facility costs are shown in Table 3.4-10 for all traffic rates to permit an incremental comparison. In addition, the Manufacturing Facility costs are summarized in Table 3.4-11 with "rate" sensitive costs for expendable elements shown. These costs reflect a 1970 cost base and a KSC construction location and are based on requirements identified in Part II, Section 3, Operation Requirements. Cost estimates for new construction and/or modifications have been based on historical data from government and contractor construction experience and from recognized pricing guides. Costs have been normalized to a 1970 base and a geographical location factor used where applicable. Major sources of government data were the publications titled:

a) Engineering Management of Design and Construction of Facilities of the National Aeronautics and Space Administration, August 11, 1969

b) Military Construction Pricing Guide, AFP 88 16, 15 April 1968

Contractor historical cost data associated with the implementation of major commercial airplane manufacturing plants and from experience with weapon system facilities provided applicable background for Space Shuttle facilities. Cost adjustment was applied to the historical costs to provide a common 1970 base by use of data published in the Construction Trade Journal - Engineering News Record.

Geographical location cost factors were used to reflect differences in labor and materials cost per AFP 88-16.

Various facilities estimating techniques were applied to gain maximum utilization of available data and included:

- DETAIL UNIT COST ($/Sq Yd, $/Cu Yd, etc.) - used for estimating items such as airports and travelways from detail quantity takeoffs
- UNIT SIZE COST ($/Sq Ft, $/Cu Ft) - used for estimating new buildings based on floor plan area or cubic volume

TABLE 3.4-9. OPERATIONS FACILITY COSTS

	Dollars in Millions					
	A-1	A-3	B-1a	B-2d	B-2i	C-4
(1) AIRPORT	17.0	17.0	17.0	17.0	17.0	17.0
(2) PURGE AREA	3.6	3.6	3.6	3.6	3.6	3.6
(3) TRAVELWAY - AIRPORT	1.3	1.3	1.3	1.3	1.3	1.3
(4) CRAWLERWAY - MAINT COMPLEX TO LAUNCH PAD	0.0	0.0	0.0	0.0	0.0	3.4
(5) ORBITER MAINTENANCE & REFURBISH FAC	0.0	0.0	6.2	0.0	0.0	0.0
(6) BOOSTER MAINTENANCE & REFURBISH FAC	2.1	0.3	0.0	5.2	0.0	29.1
(7) SOLID ROCKET MOTOR - RIS	NR	1.5	NR	NR	3.6	NR
(8) SOLID ROCKET MOTOR - STACK AND MATE FACILITY	NR	23.6	NR	NR	42.3	NR
(9) ORBITER/BOOSTER MATE FACILITY	5.4	3.2	5.4	7.8		*
(10) LAUNCH PAD	0.5	0.5	0.0	0.5	0.5	20.0
**TOTAL	29.9	51.0	33.5	35.4	68.3	74.4

*COMBINED WITH (6)
**1970 VALUE OF EXISTING LC-39 FACILITIES BEING MODIFIED OR ADDED TO IS $304 x 10^6

- LUMP SUM HISTORICAL COST ($/ITEM) - applied to facilities that are directly similar, such as new launch pads or crawlerways
- LABOR/MATERIAL ($/Hr Labor - Material $) - used for estimating structural modifications

3.4.2.3 Operational GSE Costs

The Operational GSE costs for checkout, maintenance handling and launch operations are reflected for each configuration in Table 3.4-12. The 10-year varying traffic rate costs are summarized in Table 3.4-13.

The costs reflected are based on the requirements and comparison rationale described in Part II, Section 3, Operations Requirements. "Engineering Management of Design and Construction of Facilities of the NASA (sections dealing with KSC)" is typical of historical data used in estimating new procurement or modification costs for launch systems such as mobile launchers, propellant services and firing accessories. The historical costs for S-1C Test and Checkout Stations, LM Servicing Equipment, 747 GSE and SST GSE were utilized in estimating checkout GSE procurement costs.

3.4.2.4 Transportation Costs

The size of the liquid propellant tanks and the size of the solid rocket motor segments prohibits the use of rail transportation. Transportation costs for all configurations were based on tug and barge water transportation.

The cost of the tugs and barges and operating costs were obtained from document D2-10530, Transportation of Large Boosters. It was assumed that manufacturing was accomplished at Michoud for the liquid propellant vehicles and in Georgia for the solid rocket motors. The tug and barge combination is capable of making 26 round trips a year from Georgia to the Cape and 13 round trips from New Orleans.

TABLE 3.4-10. OPERATIONS FACILITY COSTS $X10^6$

	SUMMARY					
	A1	A3	B1a	B2d	B2i	C4
DDT&E	25.2	49.0	24.4	28.7	54.2	55.0
100 FLT	0	0	0	0	0	0
220 FLT	2.9	2.0	9.1	5.4	14.1	19.4
365 FLT	4.7	2.0	9.1	5.4	14.1	19.4
445 FLT	4.7	2.0	9.1	6.7	14.1	19.4

Additional Facilities for Production and OPS Phase

TABLE 3.4-11. MANUFACTURING FACILITY COSTS (SUB-ASSEMBLY AND FINAL ASSEMBLY) FOR DDT & E AND VARYING TRAFFIC MODELS (DOLLARS x 10^6)

		A1	A3	B1a	B2d	B2i	C4
DDT&E		30.3	31.2	19.2	31.2	19.2	41.1
RECURRING PRODUCTION	NO. OF FLT						
	100	-	-	30.0	-	-	-
	220	38	68	64.0	28.0	75	-
	365	90	123	139	64.6	153	-
	445	133	194	190	89.0	153	-

TABLE 3.4-12. OPERATIONAL GSE COSTS

	Dollars in Millions					
	A-1	A-3	B-1a	B-2d	B-2i	C-4
DESIGN DEVELOPMENT						
Booster (or Strap-Ons)	35.7	35.7	---	53.0	35.7	71.4
Orbiter	107.0	107.0	107.0	107.0	107.0	107.0
PROCUREMENT						
Maintenance Checkout Equipment						
Booster (or Strap-Ons)	10.5	14.8	---	66.4	26.1	13.2
Orbiter	9.0	5.4	5.4	5.4	5.4	5.4
Mobile Launchers (Basic Structure)	* 1.0	* 4.0	* .2	21.6	17.6	N/A
Firing Accessories	* 8.0	* 8.0	* 1.0	17.0	12.6	12.0
Propellant and Pneumatic Systems	* 3.5	* 3.0	* .8	11.9	5.8	* 7.0
**TOTAL	174.7	177.9	114.4	282.3	210.2	216.0

*Modifications of Existing Equipment

**1970 Value of Existing LC-39 GSE Being Modified or Added to is $309 x 10^6

The number of tugs and barges required was determined based on the number of tanks for each configuration, the launch rate and the time required to make a round trip. A summary of the transportation costs for each configuration and flight rate is contained in Table 3.4-14. Recurring production costs reflect additional equipments to support the flight rate with new vehicles while recurring operations costs reflect crew and operating expenses.

TABLE 3.4-13. OPERATIONS GSE COST $X10^6$ SUMMARY

		A1	A3	Bla	B2d	B2i	C4
	DDT&E	161.0	163.8	110.7	223.4	175.0	204.5
Additional GSE In Production and OPS Phase	100 FLT	0	0	0	0	0	0
	220 FLT	11.6	11.3	3.7	42.3	32.3	11.5
	365 FLT	13.7	14.1	3.7	42.3	35.2	11.5
	445 FLT	13.7	14.1	3.7	58.9	35.2	11.5

TABLE 3.4-14. TRANSPORTATION COST (MAJOR ASSEMBLY) RDT&E AND VARYING TRAFFIC RATES ($x10^6$)

		A1	A3	Bla	B2d	B2i	C4
	RDT&E	1.26	1.46	0.63	1.26	1.66	0.63
	NO. OF FLT						
REC PROD	100	0.63	0.74	0.32	0.63	0.83	-
	220	1.58	1.68	1.26	3.47	2.08	-
	365	4.41	4.81	3.15	8.19	5.81	-
	445	7.25	8.90	5.99	12.92	9.55	-
REC OPS	100	8.73	8.68	4.37	8.73	8.61	.29
	220	12.23	12.74	8.43	19.21	12.05	.58
	365	20.89	20.86	13.54	31.88	19.80	.87
	445	24.02	26.51	17.47	38.86	23.68	1.16

3.5 Cost Objectives

Although the alternate space shuttle concept study does not require cost reporting in accordance with the NASA Phase B cost objectives, procedures for determining comparable cost objectives have been adapted to this study.

Briefly, the NASA Phase B cost objectives identify two discrete points in time, FMOF and program completion, and establishes a cost bogey at each, $4.5 and $7.2 billion respectively. The $4.5B cost bogey, or cost objective No. 1 (Figure 3.5-1) includes the cumulative cost for the design, development, ground test, and flight test through the first manned orbital flight (shaded area under the curve). It excludes main engine development and procurement which is under separate NASA contract. The $7.2B cost bogey, or cost objective No. 2 (Figure 3.5-2) includes the cumulative costs for a 10 year maximum traffic (445 vertical flights) program (total area under curve). Again, main engine development and procurement are excluded. In addition, both cost objectives exclude NASA operating base, contractor fees, payload costs, and other cost elements as specified by NASA.

To present costs in this format, a form was devised (Figure 3.5-2) which identified the specific cost elements to be subtracted from estimated costs to produce the appropriate cost objective.

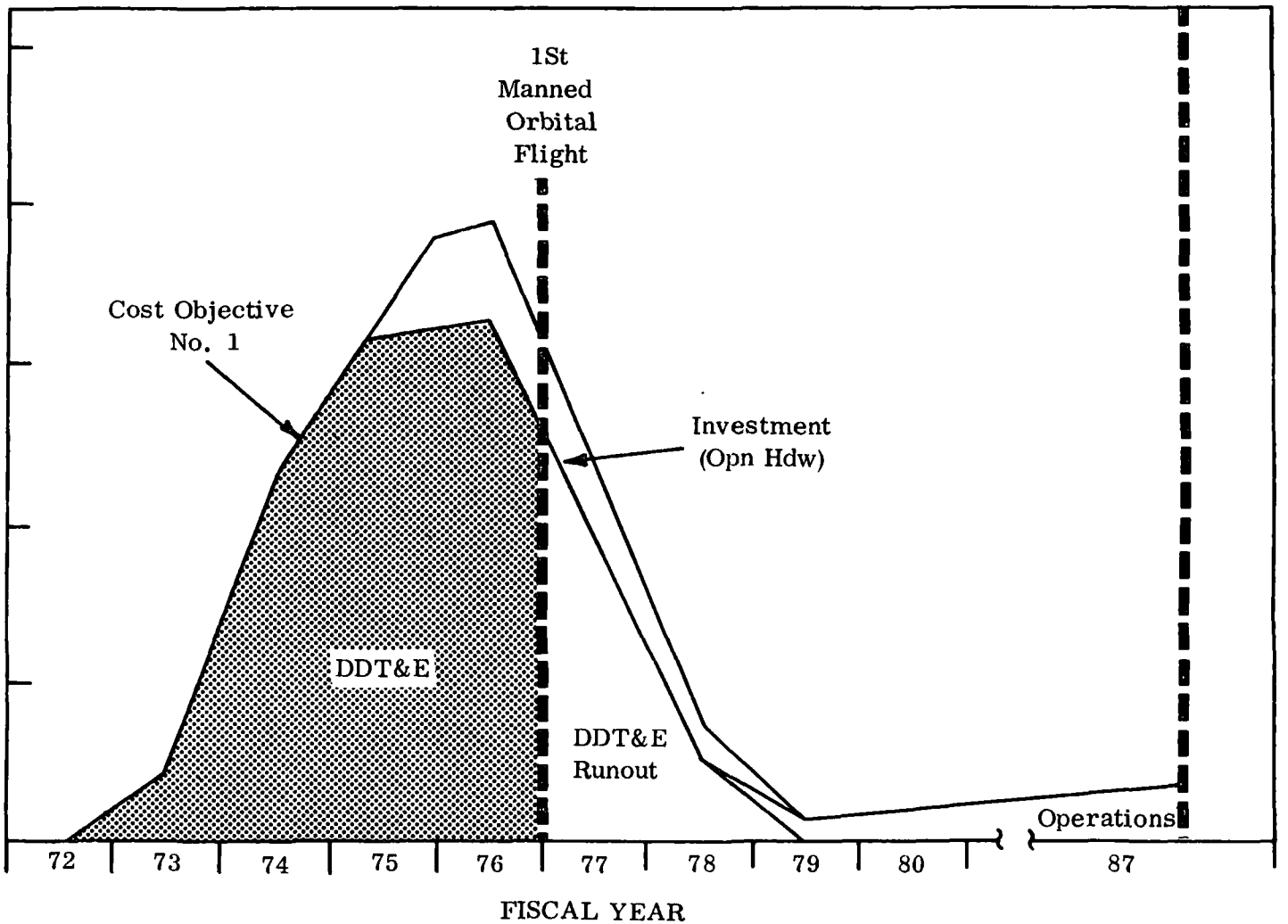


Figure 3.5-1. Cost Objective No. 1

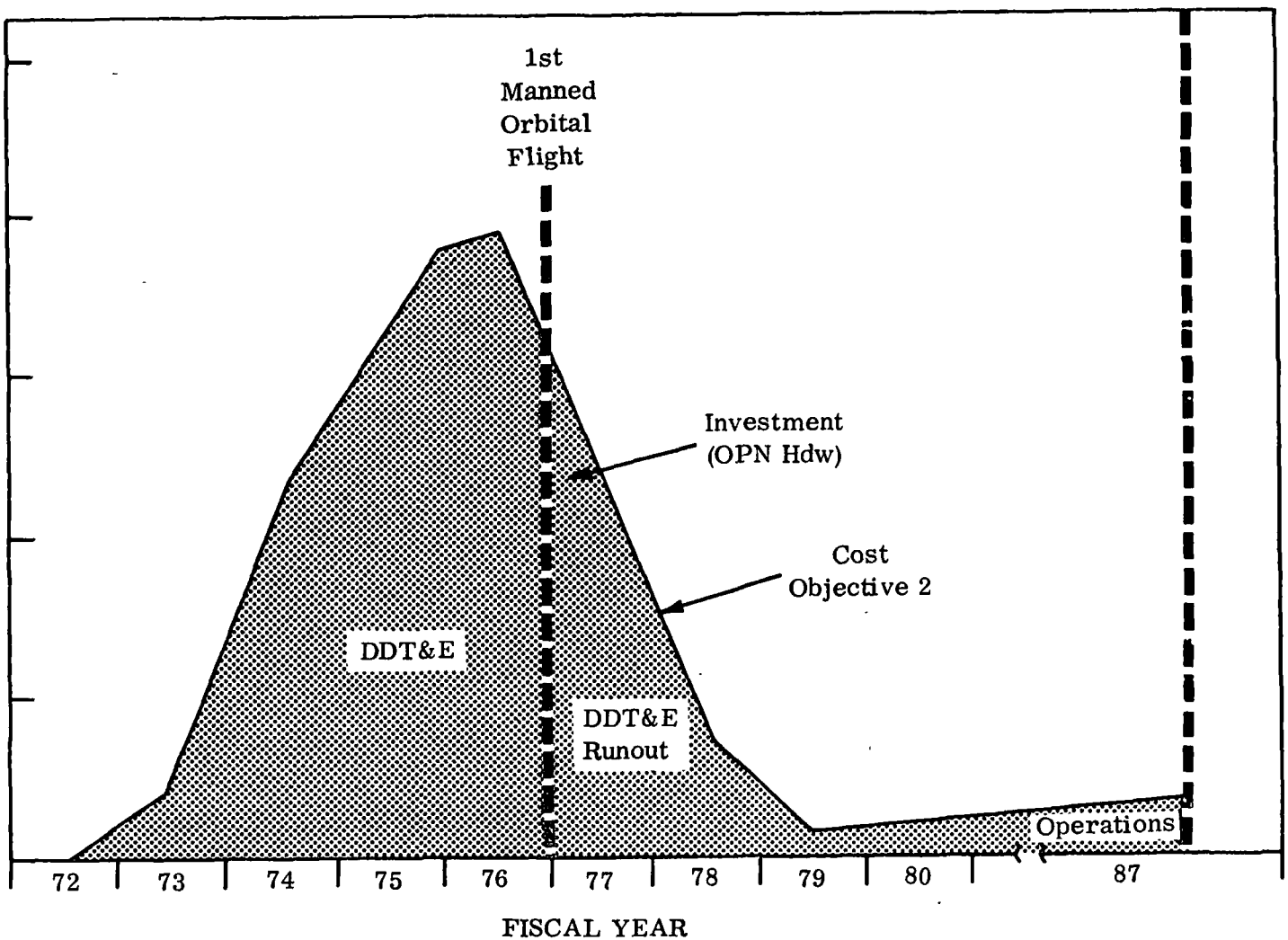


Figure 3.5-2. Cost Objective No. 2

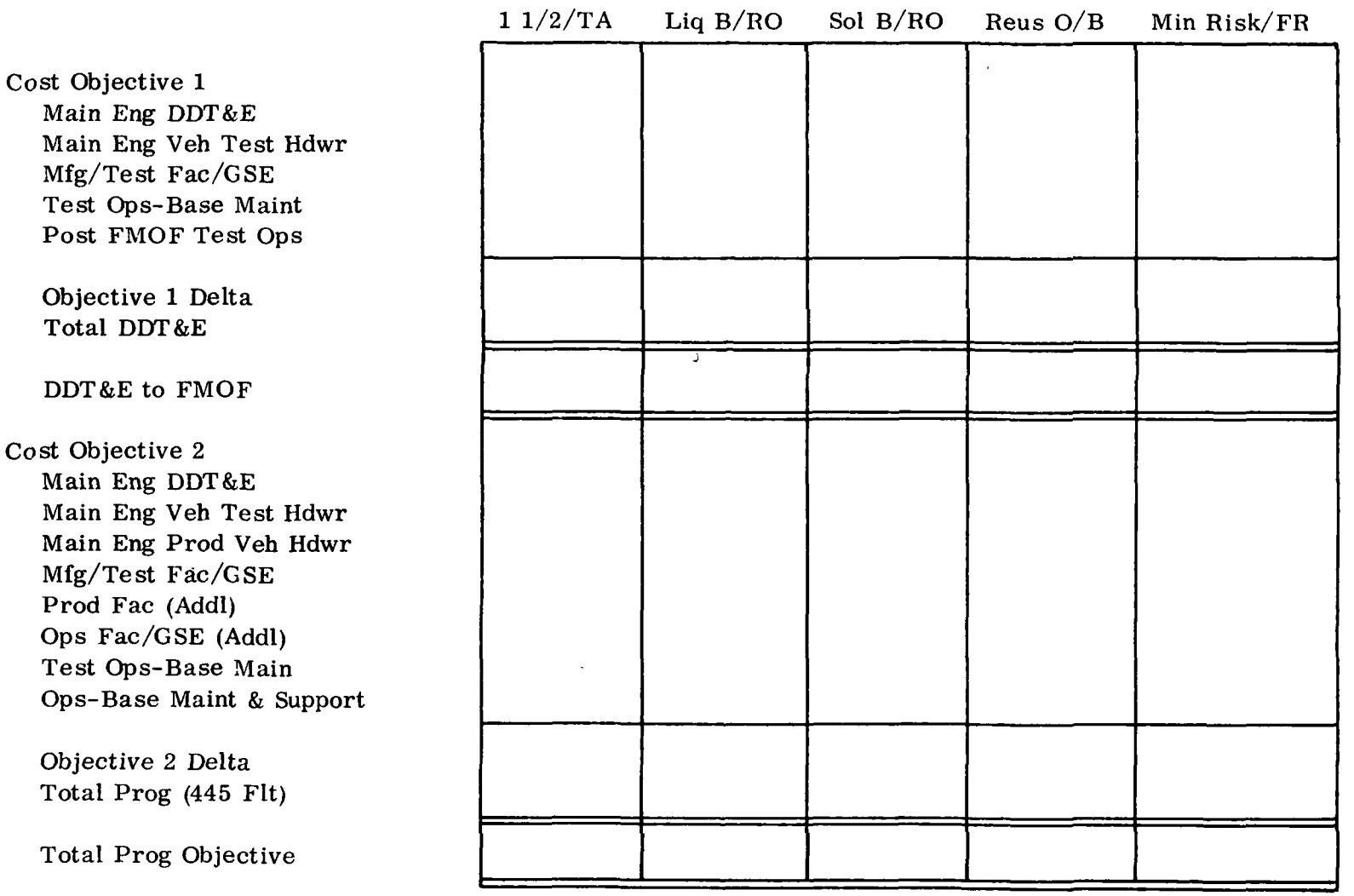


Figure 3.5-3. Program Cost Objectives.

Section 4

CONCEPT COST DATA

This section presents the results of costing the A, B and C Concept configurations previously described in Parts I and II. Cost data are reported separately, for each concept. Configuration concept costs include summary data from the mid-term reporting period as well as for the two previous reporting periods.

NASA DRD-MF003M cost forms A and D are also included for the mid-term configurations.

4.1 Concept "A"

Concept "A" consists of alternate stage and a half configurations where the reusable orbiter operates with expendable cross feed tanks and strap on motors. This section contains summaries of the system cost data developed for these configurations since July 1970.

Section 4.1.1 contains the latest cost data for the configuration remaining from the three-month and the six-weeks study reviews. Technical input data and cost data in the form of summaries, funding profiles and traffic model totals are included for that configuration.

Section 4.1.2. summarizes the data developed for the initial screening of nine "A" concept configurations and the selection of the candidate systems for the second six-week study period. Also included is a summary of the data presented at the three-month review and discussions of the subsequent efforts to define the costs for the selected configurations.

NASA cost data forms "A" and "D" for the selected configuration are submitted in Section 4.1.3.

4.1.1 Mid-Term Cost Analysis - Configuration A-3A

As a result of the three-month review, "A" concept configuration A-3A, was selected for further in-depth analysis and costing efforts. The results of these

analyses, in the form of updated technical and cost data, are contained in this section.

This section contains technical input data, cost summaries, funding profiles and total systems costs for the 445 flight, 10-year program. In addition, a description of improvements to the cost model is presented. These improvements were made after the three-month review.

A detailed weight breakdown for configuration A-3A is presented in Table 4.1-1. Tables 4.1-2 through 4.1-7 show cost program input and output data covering the mid-term analysis results.

TABLE 4.1-1. WEIGHT SUMMARY

VEL. ORB.	LOX	FUEL	*INERTS*	VEL2	PROP2	PROP1	FULL TANKS	VEL1	SOLIDS	SOL. FUEL	GLOW
0000.	551051.	155887.	170204.	17370.	1056220.	512051.	1056920.	7090.	1392000.	1232901.	3362010.

DETAILS?
1

WING	22000.
FLAP	0.0
TAIL (VERT)	5755.
TAIL (HOR)	0.0
BODY	42000.
TPS	21000.
LANDING GEAR	6557.
ROCKET	22000.
AIR BREATHER	0.0
INSTALLATION	3454.
TANKS	2702.
ORIENT. CTL.	4025.
HYDRAULICS	5575.
FIXED WTS.	6575.
CONTIN.	14033.
DRY WEIGHT	163440.
DELTA TARGET	0.0
TARGET DRY WT.	163440.
CREW	450.
RES. & RES.	650.
CARGO	25001.
LANDED WT.	189745.
PLY MORE	0.0
MAX. CRUISE WT.	189745.
RES. & RES.	5402.
OR UNUIT PROP.	10332.
RCS PROP.	3002.
INJECTION WT.	217618.
INJECT. PROP.	115275.
LOX	551051.
DROP TANK INERTS	100054.
TANK PROPELLANT	1056220.
TOTAL	1148000.
LOW2	1477333.
TOTAL SOLIDS	1392000.
TANK PROPELLANT	512051.
TOTAL	1904051.
LOX	551051.

TABLE 4.1-2. CONFIGURATION A-3A COST MODEL INPUTS - MID TERM (COMPUTER FORMAT)

A3A SHUTTLE T/W= 1.25

MACH SEA LEVEL	0.27	FLIGHT RATE NO.1.	100.00	TI PERCENT OF AMPR	0.45
MACH ALTITUDE	1.17	FLIGHT RATE NO.2.	220.00	GS MANPWR/YR. RATE 1	18.34
PROD.RATE/MO. MINE1	1.00	FLIGHT RATE NO.3.	365.00	GS MANPWR/YR. RATE 2	24.81
YEAR OF FIRST FLIGHT	1976.00	FLIGHT RATE NO.4.	445.00	GS MANPWR/YR. RATE 3	32.01
DOLLAR CONVERSION YR	1970.00	GSE+FAC. RATE 1	0.0	GS MANPWR/YR. RATE 4	36.91
		GSE+FAC. RATE 2	13.30	G+A PERCENT	0.10
		GSE+FAC. RATE 3	13.30	EQUIV.TEST ARTICLES	4.80
		GSE+FAC. RATE 4	16.10	TEST HARDWARE CONV.	10.00
APU DEV.	14.60	APU PROD.	1.59	ELECTRONIC WEIGHT	2547.00
COMS DEV.	111.00	COMS PROD.	3.78	HOURS/FLIGHT	124.00
AVIONICS DEV.	554.80	AVIONICS PROD.	66.70	NO.OF RCS ENGINES	28.00
ELEC. PWR. CRYO DEV.	11.50	ELEC. PWR. CRYO PROD	1.70	TEST OPERATIONS	197.90
ECS DEV.	60.00	ECS PROD.	1.80	TEST FACILITIES	250.40
BAT/FUEL CELLS DEV.	25.50	BAT/FUEL CELLS PROD.	2.08	NO OF TEST FLIGHTS	7.00
AIRBREATHERS DEV.	0.0	AIRBREATHERS PROD.	0.0	CRYO TANK DEV.	80.00
TPS DEV.	146.00	FUEL SYS WT-FRCT.DLV	0.93	ADDIT.PROD FAC RATE 1	0.0
TRANSPORTATION DEV.	1.48	FUEL SYS FACTOR DEV.	25.00	ADDIT.PROD FAC RATE 2	68.00
TRANSPORTATION PROD.	0.08	FUEL SYS FACTOR PROD	7.52	ADDIT.PROD FAC RATE 3	123.00
TANK INSUL. DEV.	1.78	FUEL SYS T/BASE LINE	4620000.00	ADDIT.PROD FAC RATE 4	194.00
NO.OF TEST CONVERTS	3.00	FUEL SYS WT-FRCT.PRC	0.83	NON REC MFG FAC	31.20
ENGINE FACT. DEV.	2.10	RCS FACTOR DEV.	220.00	TEST ART., 1ST STAGE	9.00
TANKAGE FACT. DEV.	1.55	RCS FACTOR 1 PROD.	3.55	TEST ART., 2ND STAGE	17.00
TANKAGE FACT. PROD.	2.67	RCS FACTOR 2 PROD.	2.25		
TPS CARBON	0.0	FLTS/TPS CARBON	1.00		
TPS RIGID INS.	0.0	FLTS/TPS RIGID INS.	1.00		
TPS COLUMBIUM	0.09	FLTS/TPS COLUMBIUM	10.00		
TPS HAYNES	0.51	FLTS/TPS HAYNES	100.00		
TPS THORIUM	0.0	FLTS/TPS THORIUM	1.00		
TPS TITANIUM	0.40	FLTS/TPS TITANIUM	100.00		
TPS RENE	0.0	FLTS/TPS RENE	1.00		
TPS ABLATIVE	0.0	FLTS/TPS ABLATIVE	1.00		
T/W STAGING	1.25	STRUCT. DENSITY	2.00	STRAPON TOT.ROCK. WT	1392000.00
TOGW CORE	3214[illegible]1.00	FRAME WT. EMPTY	102726.00	STRAPON FUEL WT.	1232901.00
TOGW COMBINED	3382010.00	TOGW MINUS SPACE SYS	138166.00	STRAPON TOT.THRUST	2627512.00
DELTA V 1ST STAGE	7096.13	FUEL WT OF CORE	132205.00	STRAPON TANK WT.FULL	1658920.00
AMPR	6434.00	THRUST/ENGINE	462000.00	STRAPON TANK WT EMP.	108644.00
DRY WEIGHT	163446.00	NO. OF ENGINES	4.00		
RCS WEIGHT	4829.00	TANK INSUL. AREA	2605.00		
TPS AREA	4427.00	INJECTION WEIGHT	217818.00		

TABLE 4.1-3. COST SUMMARY - MID TERM (COMPUTER FORMAT)

A3A SHUTTLE T/A= 1.25

COSTS IN MILLION DOLLARS

	DDT+E	AV. UNIT PROD
AIRFRAME	206.12	59.73
TANK INSULATION	1.78	0.57
TPS	146.00	2.83
FUEL SYSTEM	49.95	12.51
TANKAGE	112.60	17.45
ROCKET ENGINES	656.46	14.93
AIR BREATHING ENG.	0.0	0.0
APU	14.60	1.59
ON ORBIT MANEUV.SYS	111.00	3.78
AVIONICS	554.80	66.70
ELECT. PWR. CRYO.	11.90	1.70
BAT/FUEL CELLS	25.50	2.08
ENV. CONTROL SYS.	60.00	1.80
REACTION CONT. SYS.	212.04	5.50
TOT SUBSYSTEMS	985.84	83.15
TEST OPERATIONS	197.90	
TEST FL PROPELLANTS	1.52	
TEST AIRFRAME	286.73	
TEST TPS	13.59	
TEST FUEL SYSTEM	60.05	
TEST TANKAGE	83.75	
TEST TANK INSUL.	2.75	
TEST ENGINES	71.67	
TEST REPL. HARDWARE	2.54	
TEST 1ST STRAPON	36.18	
TEST 2ND STRAPON	92.52	
TEST SUBSYSTEMS	399.14	
TOT TEST HARDWARE	1048.91	
SUB TOTAL	3411.48	191.18
1ST STAGE STRAP-ON	106.98	3.94
1ST STAGE ENGINE		
2ND STAGE STRAP-ON	163.34	5.34
1ST STG.RECOV.DEVC.	0.0	0.0
2 PC.STRAPON SPARES		0.19
10 PC. CORE SPARES		19.12
SUB TOTAL DDT+E	3681.80	
TEST FAC/GSE	250.40	
MFG FAC NON REC.	31.20	
TRANSPORT. NON REC.	1.40	
SUB TOTAL NON REC	3964.80	
10 PC SYS INT + MGT	396.48	

TABLE 4.1-3. COST SUMMARY - MID TERM (COMPUTER FORMAT) (Cont)

TOTAL NON REC. 4261.34

OPERATIONS

PROPELLANTS/FLIGHT		0.27		
REPLENISHMENT SPARES/FLT		0.23		
OVERHAUL/FLT		0.13		
TRANSPORTATION/FLT		0.08		
TEST HARDWARE CONV.		38.50		
FAC/GSE REF.MTL./FLT, RATE	100.00	1.41		
FAC/GSE REF.MTL./FLT, RATE	220.00	0.82		
FAC/GSE REF.MTL./FLT, RATE	365.00	0.57		
FAC/GSE REF.MTL./FLT, RATE	445.00	0.55		
GS MANPOWER/YR AT RATE OF	100.	18.34		
GS MANPOWER/YR AT RATE OF	220.	24.81		
GS MANPOWER/YR AT RATE OF	365.	32.01		
GS MANPOWER/YR AT RATE OF	445.	36.91		
GSE+FACILITIES FOR RATE OF	100.	0.0		
GSE+FACILITIES FOR RATE OF	220.	13.30		
GSE+FACILITIES FOR RATE OF	365.	13.30		
GSE+FACILITIES FOR RATE OF	445.	16.10		
ADDIT.PROD FAC FOR RATE OF	100.00	0.0		
ADDIT.PROD FAC FOR RATE OF	220.00	68.00		
ADDIT.PROD FAC FOR RATE OF	365.00	123.00		
ADDIT.PROD FAC FOR RATE OF	445.00	194.00		
			SPC	TOTAL
COST PER FLIGHT AT RATE OF	100.00	11.53	0.58	12.10
COST PER FLIGHT AT RATE OF	220.00	9.54	0.48	10.02
COST PER FLIGHT AT RATE OF	365.00	8.63	0.43	9.06
COST PER FLIGHT AT RATE OF	445.00	8.41	0.42	8.83

TABLE 4.1-4. COST SPREAD - MID TERM (COMPUTER FORMAT)

CONFIGURATION FLIGHTS= 445.0
A3A SHUTTLE
R+D STG1 REC DEV STG 2, PROD STG 1 REC DEV STG 2
0.1432E 03 0.0 0.2559E 03 0.4020E 01 0.0 0.5442E 01
PROD LRN CURVE, STRAIGHT UNIT
STG 1= 0.950 REC DEV= 0.900 STG 2= 0.900
DDTE COSTS

YEAR	ORBITER	STAGE 1	STAGE 2	TEST OPS	GSE+FAC	TOTAL + 10 PC
1972.	0.5062E 02	0.2349E 01	0.4198E 01	0.3248E 01	0.4645E 01	0.7157E 02
1973.	0.2783E 03	0.1292E 02	0.2308E 02	0.1785E 02	0.2554E 02	0.3934E 03
1974.	0.5622E 03	0.2563E 02	0.4580E 02	0.3543E 02	0.5067E 02	0.7807E 03
1975.	0.7306E 03	0.3390E 02	0.6059E 02	0.4687E 02	0.6703E 02	0.1033E 04
1976.	0.7331E 03	0.3402E 02	0.6080E 02	0.4703E 02	0.6727E 02	0.1036E 04
1977.	0.5414E 03	0.2513E 02	0.4490E 02	0.3473E 02	0.4968E 02	0.7655E 03
1978.	0.1586E 03	0.9219E 01	0.1647E 02	0.1274E 02	0.1823E 02	0.2808E 03
1979.	0.0	0.0	0.0	0.0	0.0	0.0
1980.	0.0	0.0	0.0	0.0	0.0	0.0
1981.	0.0	0.0	0.0	0.0	0.0	0.0
1982.	0.0	0.0	0.0	0.0	0.0	0.0
1983.	0.0	0.0	0.0	0.0	0.0	0.0
1984.	0.0	0.0	0.0	0.0	0.0	0.0
1985.	0.0	0.0	0.0	0.0	0.0	0.0
1986.	0.0	0.0	0.0	0.0	0.0	0.0
1987.	0.0	0.0	0.0	0.0	0.0	0.0
TOTALS	0.3085E 04	0.1432E 03	0.2559E 03	0.1979E 03	0.2831E 03	0.4361E 04

PRODUCTION COSTS

YEAR	ORBITER	STAGE 1	STAGE 2	TOTAL + 5 PC
1972.	0.0	0.0	0.0	0.0
1973.	0.0	0.0	0.0	0.0
1974.	0.0	0.0	0.0	0.0
1975.	0.0	0.0	0.0	0.0
1976.	0.0	0.0	0.0	0.0
1977.	0.3850E 02	0.0	0.0	0.4042E 02
1978.	0.1052E 03	0.3602E 02	0.7954E 02	0.2318E 03
1979.	0.1052E 03	0.4881E 02	0.9542E 02	0.2619E 03
1980.	0.1052E 03	0.6181E 02	0.1143E 03	0.2953E 03
1981.	0.2691E 03	0.8911E 02	0.1579E 03	0.5735E 03
1982.	0.0	0.1148E 03	0.1963E 03	0.3267E 03
1983.	0.0	0.1395E 03	0.2312E 03	0.3893E 03
1984.	0.0	0.1633E 03	0.2638E 03	0.4485E 03
1985.	0.0	0.1865E 03	0.2946E 03	0.5052E 03
1986.	0.0	0.1962E 03	0.3040E 03	0.5252E 03
1987.	0.0	0.1933E 03	0.2947E 03	0.5124E 03
TOTALS	0.6931E 03	0.1229E 04	0.2032E 04	0.4110E 04

OPERATING COSTS

YEAR	FAC/GSE/MPR	ORB REFRB	STG1 REFRB	PRPLNTS	TOTAL+5PC	GRND TOTL
1972.	0.0	0.0	0.0	0.0	0.0	0.7157E 02
1973.	0.0	0.0	0.0	0.0	0.0	0.3934E 03
1974.	0.0	0.0	0.0	0.0	0.0	0.7807E 03
1975.	0.0	0.0	0.0	0.0	0.0	0.1033E 04
1976.	0.0	0.0	0.0	0.0	0.0	0.1036E 04
1977.	0.0	0.0	0.0	0.0	0.0	0.8059E 03
1978.	0.6310E 02	0.4431E 01	0.0	0.2742E 01	0.7379E 02	0.5864E 03
1979.	0.6310E 02	0.6647E 01	0.0	0.4114E 01	0.7756E 02	0.3394E 03
1980.	0.6310E 02	0.8863E 01	0.0	0.5485E 01	0.8133E 02	0.3766E 03
1981.	0.6310E 02	0.1329E 02	0.0	0.8227E 01	0.8886E 02	0.6623E 03
1982.	0.6310F 02	0.1773E 02	0.0	0.1097E 02	0.9639E 02	0.4231E 03
1983.	0.6310E 02	0.2216E 02	0.0	0.1371E 02	0.1039E 03	0.4932E 03
1984.	0.6310E 02	0.2659E 02	0.0	0.1645E 02	0.1115E 03	0.5599E 03
1985.	0.6310E 02	0.3102E 02	0.0	0.1920E 02	0.1190E 03	0.6241E 03
1986.	0.6310E 02	0.3324E 02	0.0	0.2057E 02	0.1228E 03	0.6480E 03
1987.	0.6310E 02	0.3324E 02	0.0	0.2057E 02	0.1228E 03	0.6352E 03
TOTALS	0.6310E 03	0.1972E 03	0.0	0.1220E 03	0.9578E 03	0.9469E 04

TABLE 4.1-5. DISCOUNTED COST SPREAD - MID TERM (COMPUTER FORMAT)

INTEREST RATES & TOTAL PRESENT VALUES
BASE YEAR= 1970.

2.00	0.7719E 04	4.00	0.6363E 04	6.00	0.5301E 04	8.00	0.4460E 04
10.00	0.3785E 04	12.00	0.3240E 04	14.00	0.2793E 04	16.00	0.2425E 04
18.00	0.2119E 04	20.00	0.1862E 04				

DISCOUNTED CASH FLOW AT 10.000 -

YEAR	ANN. COST	CUM.	DISCOUNT	CUM.
1972.	0.7157E 02	0.7157E 02	0.5377E 02	0.5377E 02
1973.	0.3934E 03	0.4650E 03	0.2647E 03	0.3225E 03
1974.	0.7807E 03	0.1246E 04	0.4948E 03	0.8073E 03
1975.	0.1033E 04	0.2279E 04	0.5930E 03	0.1390E 04
1976.	0.1036E 04	0.3315E 04	0.5319E 03	0.1922E 04
1977.	0.8059E 03	0.4121E 04	0.3760E 03	0.2298E 04
1978.	0.5864E 03	0.4707E 04	0.2487E 03	0.2547E 04
1979.	0.3394E 03	0.5047E 04	0.1309E 03	0.2678E 04
1980.	0.3766E 03	0.5423E 04	0.1320E 03	0.2810E 04
1981.	0.6623E 03	0.6086E 04	0.2110E 03	0.3021E 04
1982.	0.4231E 03	0.6509E 04	0.1225E 03	0.3143E 04
1983.	0.4932E 03	0.7002E 04	0.1299E 03	0.3273E 04
1984.	0.5599E 03	0.7562E 04	0.1340E 03	0.3407E 04
1985.	0.6241E 03	0.8186E 04	0.1358E 03	0.3543E 04
1986.	0.6480E 03	0.8834E 04	0.1282E 03	0.3671E 04
1987.	0.6352E 03	0.9469E 04	0.1142E 03	0.3785E 04

TOTAL= 0.3785E 04

INTEREST RATES & TOTAL PRESENT VALUES
BASE YEAR= 1970.

2.00	0.7719E 04	4.00	0.6363E 04	6.00	0.5301E 04	8.00	0.4460E 04
10.00	0.3785E 04	12.00	0.3240E 04	14.00	0.2793E 04	16.00	0.2425E 04
18.00	0.2119E 04	20.00	0.1862E 04				

DISCOUNTED CASH FLOW AT 5.000 -

YEAR	ANN. COST	CUM.	DISCOUNT	CUM.
1972.	0.7157E 02	0.7157E 02	0.6182E 02	0.6182E 02
1973.	0.3934E 03	0.4650E 03	0.3237E 03	0.3855E 03
1974.	0.7807E 03	0.1246E 04	0.6117E 03	0.9972E 03
1975.	0.1033E 04	0.2279E 04	0.7707E 03	0.1768E 04
1976.	0.1036E 04	0.3315E 04	0.7366E 03	0.2505E 04
1977.	0.8059E 03	0.4121E 04	0.5435E 03	0.3050E 04
1978.	0.5864E 03	0.4707E 04	0.3780E 03	0.3428E 04
1979.	0.3394E 03	0.5047E 04	0.2094E 03	0.3638E 04
1980.	0.3766E 03	0.5423E 04	0.2202E 03	0.3857E 04
1981.	0.6623E 03	0.6086E 04	0.3688E 03	0.4225E 04
1982.	0.4231E 03	0.6509E 04	0.2244E 03	0.4450E 04
1983.	0.4932E 03	0.7002E 04	0.2491E 03	0.4699E 04
1984.	0.5599E 03	0.7562E 04	0.2693E 03	0.4968E 04
1985.	0.6241E 03	0.8186E 04	0.2859E 03	0.5254E 04
1986.	0.6480E 03	0.8834E 04	0.2827E 03	0.5537E 04
1987.	0.6352E 03	0.9469E 04	0.2639E 03	0.5801E 04

TOTAL= 0.5801E 04

TABLE 4.1-6. A-3 COST SUMMARY - MIDTERM - 445 FLIGHTS

• DDT&E - TOTAL ($M)	4361	
Core Vehicle		2162.8
Stage 1 (SRM)		106.9
Stage 2 (Drop Tanks)		163.3
Test Vehicles		1049.0
Test OPS		199.8
Test Facility/GSE		250.4
Mfg. Facility		32.7
Sys. Int./Mgmt.		396.5
• PRODUCTION - TOTAL	4110	
Core Vehicle		420.7
Stage 1 (SRM)		1229.0
Stage 2 (Drop Tanks)		2032.0
Test Veh Conversion		38.5
Prod. Fac. (Add'l.)		194.0
Sys. Int./Mgmt.		195.7
• OPERATIONS - TOTAL	997.8	
OPS & Support		369.1
Materials		319.2
OPS Fac/GSE (Add'l.)		261.9
Sys. Int./Mgmt.		47.5
• TOTAL PROGRAM	9469	

TABLE 4.1-7. COST SUMMARY BY FLIGHT RATE

PROGRAM	FLIGHT RATE			
	100	220	365	445
DDT&E	4361	4361	4361	4361
PRODUCTION	963.6	1957	3268	4110
OPERATIONS	415.7	630.7	844.4	997.8
TOTAL	5741	6949	8473	9469
PEAK ANNUAL FUNDING	1036	1036	1036	1036

4.1.2 Concept A Configuration Cost Comparisons

This section presents the cost data developed to assist in screening the nine initial "A" concept configurations.

Technical characteristics and profile drawings of each configuration are shown in Section 2.1.

Also included are the six-week/three-month cost refinements and a summary of the data presented at the three-month review.

4.1.2.1 6-Week Comparison

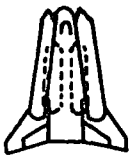
6-week cost comparison was the first, rough estimate of the various "A" concept costs. It resulted in the selection of two candidate concepts for further study, A-2 and A-3.

The initial study matrix comprised the nine configurations shown in Table 4.1-8. All configurations had one or more strap-on elements to provide both increased performance, and to limit the staging velocity of the first stage strap-ons where recovery was desirable.

In summary the nine configurations were:

- Configurations A-1 and A-2 - All thrust in the core vehicle with new high pressure, topping cycle engines and two sets of strap-on cryogenic tanks, the first set recoverable on A-2
- Configurations A-3 and A-4 - Thrust augmentation in 120-inch SRM first stage strap-on with A-3 expendable and A-4 recoverable, new high pressure topping cycle engines in the core vehicles with second stage strap-ons being expendable drop tanks
- Configurations A-5 and A-6 - Thrust augmentation in 156-inch SRM first stage strap-on with A-5 expendable and A-6 recoverable, J-2S engines in the core vehicles with second stage expendable drop tanks

TABLE 4.1-8. CONCEPT "A" - COSTED POINT DESIGN SUMMARY - 6 WEEKS

									
Configuration	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9
1st Stage Engines	-	-	120 SRM	Recoverable 120 SRM	156 SRM	Recoverable 156 SRM	Press Fed Hypergolic	J25	HIP_c
L. O. W.	1887000	1962000	1655000	1694000	2605000	2770000	2809000	1084000	753000
Core Engines	HIP_c	HIP_c	$4/HIP_c$	$4/HIP_c$	6/J2S	6/J2S	6/J2S	6/J2S	$3/HIP_c$
Thrust	3950000	4065000	1600000	1600000	1180000	1180000	1180000	1180000	1200000
ΔV	4000	4000	8000	8000	8000	8000	8000	8000	6000
O. L. O. W.	420000	426000	400000	400000	410000	410000	410000	410000	301000
Glow	3439000	3535000	3652000	3790000	4386000	4550000	4645000	2947000	2411000

- Configuration A-7 - Thrust augmentation in expendable pressure-fed hypergolic first stage strap-ons, J-2S engines in the core vehicle, and second stage expendable drop tanks

- Configuration A-8 - Thrust augmentation in recoverable J-2S engined first stage strap-ons, J-2S engines in the core vehicle, and second stage expendable drop tanks

- Configuration A-9 - Thrust augmentation in recoverable high pressure topping cycle engined first stage strap-ons, the same engines in the core vehicle, and second stage expendable drop tanks

Summary results of the comparison of these configurations is presented in Table 4.1-9 and in Figure 4.1-1.

4.1.2.2 6-Week - 3 Month Cost Refinements

The initial study matrix was evaluated using the GAC Space Shuttle Cost Model. As design data continued to be expanded in technical areas, the CER's used to formulate the cost components were re-evaluated with respect to cross feed complexities and in some cases refined through consultation with personnel from Grumman engineering, manufacturing, test and operations. Vendor data was incorporated as it became available. Significant differences present in the 3-month evaluation were:

a) More precise definition of the number and configuration of the test vehicles.

b) Production quantities. (Core Vehicles)

Flight	6 week	12 Week
100	1	0
220	2	0
365	3	1
445	4	2

TABLE 4.1-9. "A" SUMMARY EVALUATION - 6 WEEKS

SCREENING FACTOR	UNITS	A_1 4 D.T. EXP	A_2 2 EXDT. 2 RECDT	A_3 EX. 120"	A_4 REC. 120"	A_5 EX. 156"	A_6 REC. 156"	A_7 EX. STOR.	A_8 REC. J2S	A_9 REC. HiPc
PEAK ANNUAL FUNDING	B $	1.0	1.1	.92	1.0	.96	.90	.82	1.0	.91
TOTAL PROGRAM COST	B $	9.25	9.15	9.3	10.4	9.7	10.6	8.3	14.2	13.2
PAYLOAD SENSITIVITY	LB/%W_{I1}	192	192	145	175	238	280	288	120	64
	LB/%W_{I2}	360	360	415	415	356	356	334	362	435
	LB/SEC_T	2000	2000	1560	1560	1700	1700	1720	1480	1400

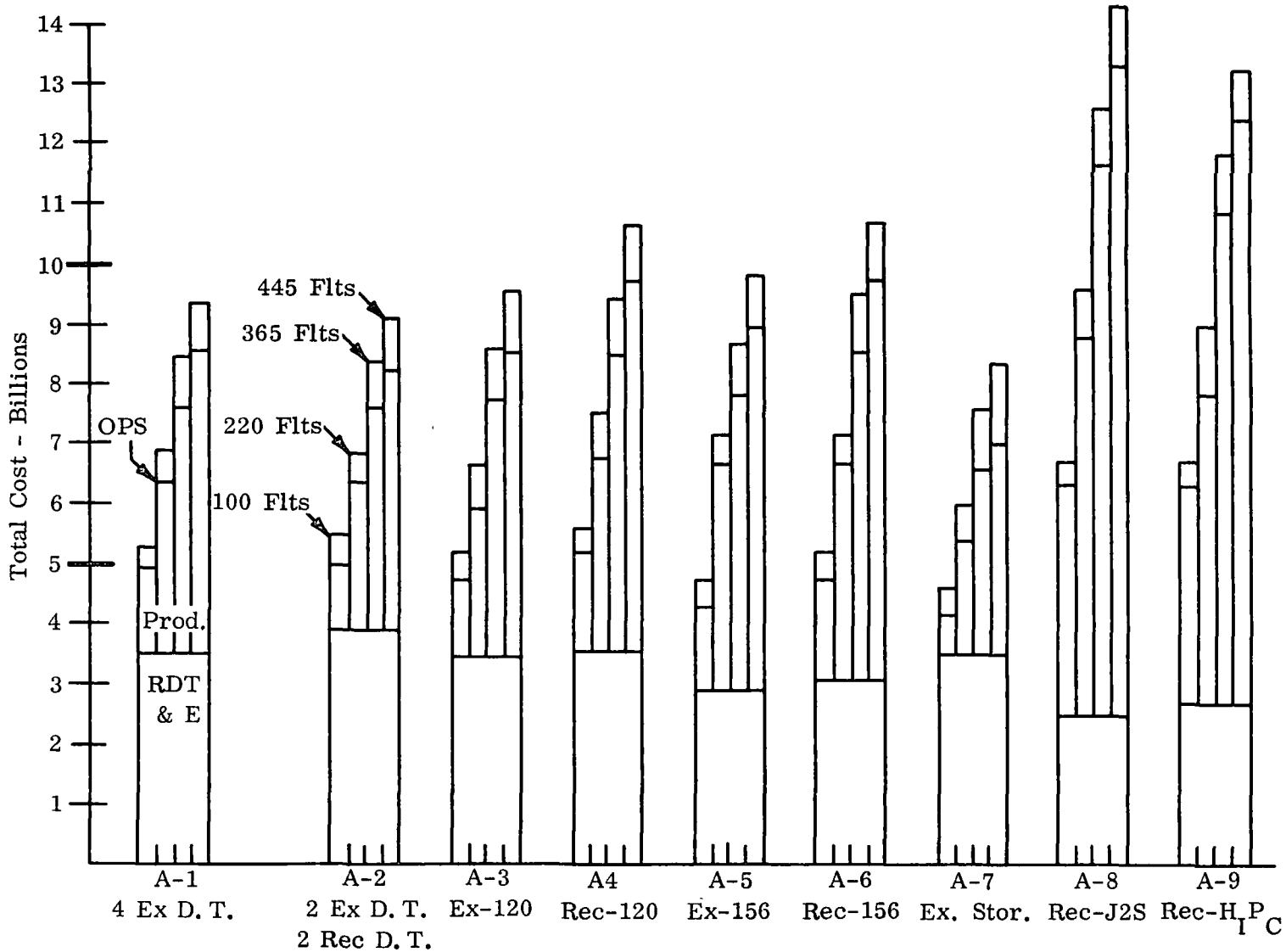


Figure 4.1-1. Concept A - Cost Comparison - 6 Weeks

c) The TPS material cost was altered to reflect latest manufacturing data.

d) Tanks and fuel system were extracted from basic AMPR and costed separately.

e) Provision was made for systems integration and management categories.

4.1.2.3 *3-Month Concept Comparison*

A-1A and A-3A were costed using the cost refinements presented in 4.1.2.2. The results of this effort follow on Figures 4.1-2 and 4.1-3, and on Tables 4.1-10 through 4.1-12.

4.1.2.4 3-Month to Mid-term Cost Refinements

The following changes were made to the cost model since the 3-month reporting period:

DDT&E

- Cryogenic tankage cost equation was modified to show a more realistic relationship

Production

- An improved CER (cost estimating relationship) was used to predict SRM (solid rocket motor) costs for A-3A. Each of the above changes resulted in a cost reduction

A STAGE AND A HALF, (445 FLIGHTS)

	A-1A	A-3A
	All Engines In Core, Double Staging of Expendable Tanks	SRM Assisted Launch, 1 Set Drop Tanks
• DDT&E, $B	5.61	4.35
• Total Program, $B	12.76	9.87
• Cost/Flight, $M – (No Amortized Production)	12.7	10.9
• Peak Annual Funding $B	1.43	1.10
• Payload Sensitivity ($Lbs\%W_i$)	4876	2613
• Cost Sensitivity		
($M/\%\Delta W_i$)	681	276
($M/\%\Delta Isp$)	845	885

Figure 4.1-2. - Concept A - 3 Month Comparison

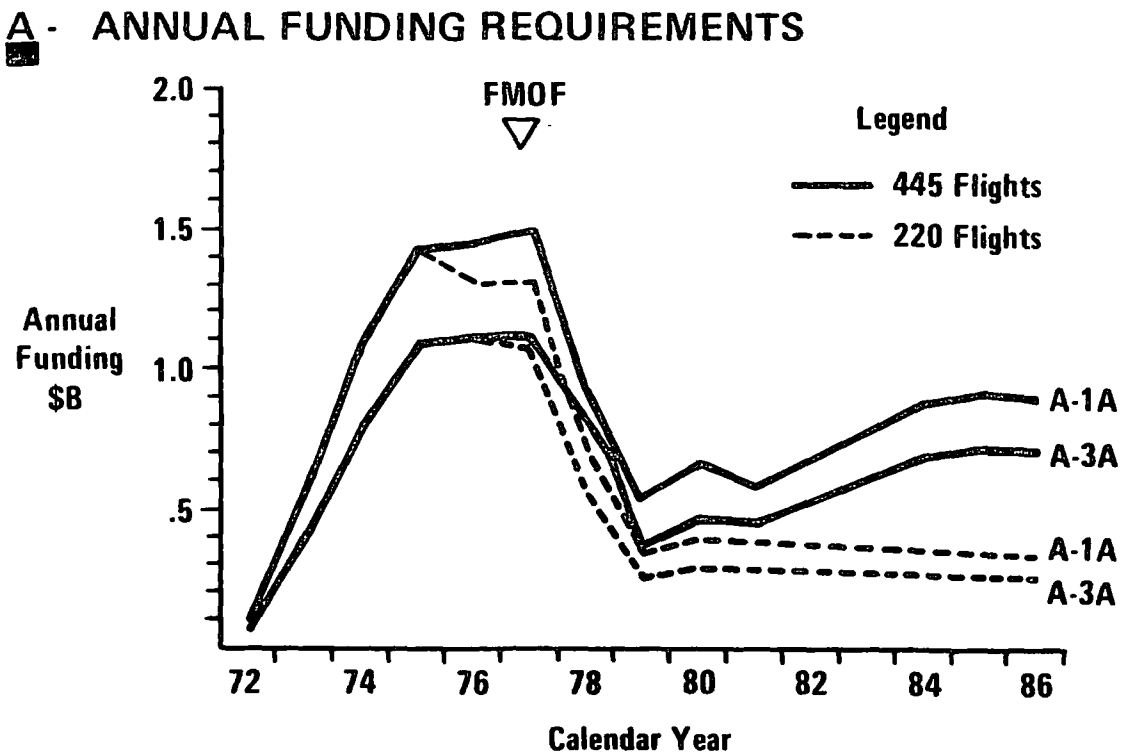


Figure 4.1-3. A - Annual Funding Requirements - 3 Months

TABLE 4.1-10. A CHARACTERISTICS SUMMARY - 3 MONTHS

A CHARACTERISTICS SUMMARY

	A-1A	A-3A
GLOW	4,496,400	3,382,000
o Core Vehicle		
- ΔV	4,000	6,000
- Low	569,470	331,089
- Propellant - Injection	138,710	113,253
- No. Engines	10	4
- Thrust/Engines - SL	562,000	400,000
o Second Stage Strap-On		
- ΔV	12,400	17,370
- Tank Weight Total	929,822	1,658,913
- Propellant - Total	868,178	1,550,271
o First Stage Strap-On		
- ΔV	14,000	7,100
- Tank Weight Total	2,997,108	------
- SRM Wt (1)	------	1,392,000
- Propellant - Total	2,803,849	1,232,901
- SRM Thrust - SL	------	2,640,000

TABLE 4.1-11. COST SUMMARY, CONCEPT A - 3 MONTHS

		A-1A		A-3A
• DDT&E - Total ($ B)	5.61		4.35	
Core Vehicle		2.54		2.14
Booster (Tanks & SRM)		0.42		0.27
Test Vehicles		1.68		1.03
Test Ops & Support		0.20		0.20
Test Fac/GSE		0.23		0.25
Mfg Fac		0.03		0.03
Sys Int/Mgt		0.50		0.43
• Production - Total	5.90		4.63	
Core Vehicle		0.72		0.42
*Booster (Tanks & SRM)		4.70		3.71
Test Veh Conversion		0.04		0.05
Prod Fac (Add'l)		0.16		0.23
Sys Int/Mgt		0.28		0.22
• Operations - Total	1.25		0.89	
Ops & Support		0.36		0.36
Materials		0.81		0.43
Ops Fac/GSE (Add'l)		0.02		0.02
Sys Int/Mgt		0.06		0.08
• Total Program	12.76		9.87	

*95% cumulative avg. learning factor applied to SRM's, 90% applied to expendable tanks.

TABLE 4.1-12. A DETAILED COSTS, DDT&E - 3 MONTHS

A DETAILED COSTS, DDT&E

	A-1A	A-3A
• Core Vehicle		
- Structure	$.430B	$.206B
- Main Tanks	.089	.093
- TPS	.162	.146
- Main Propulsion	.064	.050
- OMS	.111	.111
- ACPS/TVC	.274	.212
- Avionics	.555	.555
- Power	.052	.052
- ECLSS	.060	.060
- Main Engine	.745	.656
- Core Vehicle - Total	$2.542B	$2.141B
• Strap-Ons		
- Tanks	$.420	$.160
- SRM		.110
• Vehicle Total	$2.96B	$2.41B

Operations

- GSE facilities annual refurbishment materials cost was added
- TPS refurbishment cost equation was modified to describe these costs more realistically

4.1.3 NASA Cost Form

This section includes completed NASA cost estimate form "A" and "D" (Ref. MF003M) for configuration A-3A.

The forms display total cost and fiscal year distribution for A-3A.

DDT&E	Figure 4.1-4 & 5
PRODUCTION	Figure 4.1-6 & 7
OPERATIONS	Figure 4.1-8 & 9

COST ESTIMATE DATA FORM A

Date_____

___x Non-Recurring (DDT&E)

Page_____ of____

____ Recurring (Production)

____ Recurring (Operations)

VEHICLE CONFIGURATION A3A

NO. OF FLTS. 445

WBS IDENTIFICATION NO.	WBS ITEM NAME	WBS ITEM COST ($MILL)	NUMBER OF UNITS
	Orbiter	2599.7	3
	Booster	454.8	14 TANKS + 7 SRM'S
	Main Engine	656.5	-
	Flight Test	253.9	-
	Program Management	396.5	-

Figure 4.1-4. Cost Estimate Data Form A - A-3A (DDT&E)

COST ESTIMATE DATA FORM D

Date _____

x Non-Recurring (DDT&E)

Page _____ of ____

___ Recurring (Production)

VEHICLE CONFIGURATION A3A

___ Recurring (Operations)

NO OF FLTS. 445

PROJECT WBS ITEMS	FY 72	FY 73	FY 74	FY 75	FY 76	FY 77	FY 78	FY 79
Orbiter	8.5	172.1	460.0	659.3	659.2	460	172.1	8.5
Booster	1.0	22	62	97	112	97	56.8	7.0
Main Engine	2.0	43.1	116	167.1	167.1	116.1	43.1	2.0
Flight Test	.33	7.0	24	44	59.8	63.77	47.0	8.0
Program Management	26.4	52.9	52.9	52.9	52.9	52.9	52.9	52.7

Figure 4.1-5. Cost Estimate Data Form D - A-3A (DDT&E)

COST ESTIMATE DATA FORM A

____ Non-Recurring (DDT&E)

__x__ Recurring (Production)]

____ Recurring (Operations)

Date _____

Page _____ of _____

VEHICLE CONFIGURATION A3A

NO. OF FLTS. 445

WBS IDENTIFICATION NO.	WBS ITEM NAME	WBS ITEM COST	NUMBER OF UNITS
	Orbiter	387.8	2
	Booster	3299.5	890 TANKS + 445 SRM
	Main Engine	32.8	8
	Flight Test	*	
	Program Management	195.6	

*Costs Included In Orbiter & Booster Costs

Figure 4.1-6. Cost Estimate Data Form A - A-3A (Production)

COST ESTIMATE DATA FORM D

Date _____

_____ Non-Recurring (DDT&E)

Page _____ of _____

__x__ Recurring (Production)

_____ Recurring (Operations)

VEHICLE CONFIGURATION A3A

NO. OF FLTS. 445

PROJECT WBS ITEMS	FY		FY		FY		FY		FY		FY		FY
	77	78	79	80	81	82	83	84	85	86	87	88	89 90
Orbiter	67.7	116.2	96.9	96.9	48.6								
Booster	--	57.79	129.90	160.17	308.56	376.01	340.8	398.9	454.1	490.7	494.1	244	
Main Engine	4.10	8.20	8.20	8.20	4.10								
Flight Test	*	*	*	*									
Program Management	8.9	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	8.7	
*Costs Included in Orbiter & Booster Costs													

Figure 4.1-7. Cost Estimate Data Form D - A-3A (Production)

COST ESTIMATE DATA FORM A

____ Non-Recurring (DDT&E)

____ Recurring (Production)

__x__ Recurring (Operations)

Date_____

Page_____ of____

VEHICLE CONFIGURATION A3A

NO. OF FLTS. 445

WBS IDENTIFICATION NO.	WBS ITEM NAME	WBS ITEM COST	NUMBER OF UNITS
	Operations	950.0	
	Program Management	47.5	

Figure 4.1-8. Cost Estimate Data Form A - A-3A (Operations)

COST ESTIMATE DATA FORM D

Date_____

_____ Non-Recurring (DDT&E)

Page_____ of_____

_____ Recurring (Production)

__X__ Recurring (Operations)

VEHICLE CONFIGURATION A3A

NO. OF FLTS. 445

PROJECT WBS ITEMS	FY		FY		FY		FY		FY		FY	
	77	78	79	80	81	82	83	84	85	86	87	88
Operations	137.6	153.8	44.09	47.35	53.52	60.99	68.36	75.88	43.40	89.04	90.96	45.42
Program Management	2.4	4.2	4.2	4.2	4.3	4.3	4.3	4.3	4.3	4.3	4.3	2.4

Figure 4.1-9. Cost Estimate Data Form D - A-3A (Operations)

4.2 Concept "B"

Concept "B" consists of alternate space shuttle configurations using expendable boosters with recoverable orbiters. This section contains summaries of the system cost data developed for these configurations since July 1970.

Section 4.2.1 contains the latest cost data for the configurations remaining from the three month and the six weeks study reviews. Technical input data and cost data in the form of summaries, funding profiles and traffic model totals are included for each of the configurations.

Section 4.2.2 summarizes the data developed for the initial screening of 16 "B" concept configurations and the selection of the candidate systems for the second six week study period. Also included is a summary of the data presented at the three month review and discussions of the subsequent efforts to refine the costs for the selected configurations.

NASA cost data forms "A" and "D" for the selected configurations are submitted in Section 4.2.3.

4.2.1 Configuration Cost

As a result of the three month review, "B" concept configurations B-1A, B-2D, and B-2I were selected for further in depth analysis and costing efforts. The result of these analyses, in the form of updated technical and cost data, are contained in this section.

Section 4.2.1.1 reports the cost data on configuration B-1A. Similar data for configurations B-2D and B-2I are included in Section 4.2.1.2.

Each section contains technical input data, cost summaries, funding profiles and total systems costs for the various traffic models.

The orbiter weight and costs used in all B configurations are presented in Tables 4.2-1 thru 4.2-5.

A summary of the costed point designs are shown in Table 4.2-6.

TABLE 4.2-1. POINT DESIGN WEIGHT SUMMARY B2 ORBITER

WING	24055.
FLAP	0.0
TAIL (CTR.)	3206.
TAIL (OBD)	5959.
BODY	61056.
TPS	32550.
LANDING GEAR	7520.
ROCKET	11515.
AIR BREATHER	0.0
INSTALLATION	5750.
TANKS	1001.
ORIENT. CTL.	5000.
HYDRAULICS	6110.
FIXED WTS.	7210.
CONTIN.	17407.
DRY WEIGHT	151475.
DELTA TARGET	0.0
TARGET DRY WT.	151475.
CREW	400.
RES. & RES.	1550.
CARGO	25001.
LANDED WT.	218432.
FLY HOME	0.0
MAX. CRUISE WT.	218432.
RES. & RES.	3534.
ON ORBIT PROP.	22109.
RCS PROP.	4225.
INJECTION WT.	254514.
INJECT. PROP.	491525.
LOW	745964.
HIGH	0.0

TABLE 4.2-2. ORBITER COST PROGRAM INPUTS

B-2 ORBITER T/W= 1.25

MACH SEA LEVEL	0.27	FLIGHT RATE NO.1.	100.00	TI PERCENT OF AMPR	0.63
MACH ALTITUDE	1.00	FLIGHT RATE NO.2.	220.00		
PROD.RATE/MO. MIN=1	1.00	FLIGHT RATE NO.3.	365.00		
YEAR OF FIRST FLIGHT	1976.00	FLIGHT RATE NO.4.	445.00		
DOLLAR CONVERSION YR	1970.00	GSE+FAC. RATE 1	0.0		
				G+A PERCENT	0.10
				EQUIV.TEST ARTICLES	3.70
				TEST HARDWARE CONV.	10.00
APU DEV.	14.60	APU PROD.	1.60	ELECTRONIC WEIGHT	2547.00
OOMS DEV.	111.00	OOMS PROD.	3.78	HOURS/FLIGHT	124.00
AVIONICS DEV.	520.00	AVIONICS PROD.	64.00	NO.OF RCS ENGINES	22.00
ELEC. PWR. CRYO DEV.	10.80	ELEC. PWR. CRYO PROD	1.70	TEST OPERATIONS	97.30
ECS DEV.	60.00	ECS PROD.	1.80		
BAT/FUEL CELLS DEV.	25.50	BAT/FUEL CELLS PROD.	2.08	NO OF TEST FLIGHTS	3.00
AIRBREATHERS DEV.	0.0	AIRBREATHERS PROD.	0.0	CRYO TANK DEV.	80.00
TPS DEV.	120.00	FUEL SYS WT-FRCT.DEV	0.96	ADDIT.PROD FAC RATE1	0.0
TRANSPORTATION DEV.	0.0	FUEL SYS FACTOR DEV.	13.00	ADDIT.PROD FAC RATE2	0.0
TRANSPORTATION PROD.	0.0	FUEL SYS FACTOR PROD	2.90	ADDIT.PROD FAC RATE3	0.0
TANK INSUL. DEV.	1.59	FUEL SYS T/BASE LINE	800000.00	ADDIT.PROD FAC RATE4	0.0
NO.OF TEST CONVERTS	2.00	FUEL SYS WT-FRCT.PRC	0.86	NON REC MFG FAC	0.0
ENGINE FACT. DEV.	2.10	RCS FACTOR DEV.	220.00	TEST ART.. 1ST STAGE	0.0
TANKAGE FACT. DEV.	1.53	RCS FACTOR 1 PROD.	4.26	TEST ART.. 2ND STAGE	0.0
TANKAGE FACT. PROD.	3.10	RCS FACTOR 2 PROD.	2.70		
TPS CARBON	0.0	FLTS/TPS CARBON	1.00		
TPS RIGID INS.	0.0	FLTS/TPS RIGID INS.	1.00		
TPS COLUMBIUM	0.17	FLTS/TPS COLUMBIUM	10.00		
TPS HAYNES	0.56	FLTS/TPS HAYNES	100.00		
TPS THORIUM	0.0	FLTS/TPS THORIUM	1.00		
TPS TITANIUM	0.23	FLTS/TPS TITANIUM	100.00		
TPS RENE	0.0	FLTS/TPS RENE	1.00		
TPS ABLATIVE	0.04	FLTS/TPS ABLATIVE	1.00		
T/W STAGING	1.25	STRUCT. DENSITY	1.60	STRAPON TOT.ROCK. WT	0.0
TOGW CORE	745460.00	FRAME WT. EMPTY	133758.44	STRAPON FUEL WT.	0.0
TOGW COMBINED	745460.00	TOGW MINUS SPACE SYS	174493.19	STRAPON TOT.THRUST	0.0
DELTA V 1ST STAGE	15870.00	FUEL WT OF CORE	514062.50	STRAPON TANK WT.FULL	0.0
AMPR	1160556	THRUST/ENGINE	465912.50	STRAPON TANK WT EMP.	0.0
DRY WEIGHT	190662.75	NO. OF ENGINES	2.00		
RCS WEIGHT	5838.04	TANK INSUL. AREA	5806.31		
TPS AREA	6200.97	INJECTION WEIGHT	253424.56		

TABLE 4.2-3. ORBITER COST PROGRAM OUTPUT

8-2 ORBITER T/U= 1.25

COSTS IN MILLION DOLLARS

	DDT+E	AV. UNIT PROD
AIRFRAME	235.74	74.54
TANK INSULATION	1.59	1.28
TPS	120.00	4.92
FUEL SYSTEM	32.17	7.40
TANKAGE	115.14	24.29
ROCKET ENGINES	658.56	7.51
AIR BREATHING ENG.	0.0	0.0
APU	14.60	1.60
ON ORBIT MANEUV.SYS	111.00	3.78
AVIONICS	520.00	64.00
ELECT. PWR. CRYO.	10.60	1.70
BAT/FUEL CELLS	25.50	2.08
ENV. CONTROL SYS.	60.00	1.80
REACTION CONT. SYS.	224.60	6.60
TOT SUBSYSTEMS	966.50	81.56
TEST OPERATIONS	97.30	
TEST FL PROPELLANTS	0.25	
TEST AIRFRAME	275.61	
TEST TPS	18.19	
TEST FUEL SYSTEM	27.37	
TEST TANKAGE	89.86	
TEST TANK INSUL.	4.73	
TEST ENGINES	27.60	
TEST REPL. HARDWARE	1.79	
TEST 1ST STRAPON	0.0	
TEST 2ND STRAPON	0.0	
TEST SUBSYSTEMS	301.75	
TOT TEST HARDWARE	747.30	
SUB TOTAL	2974.55	201.49
1ST STAGE STRAP-ON	0.0	0.0
1ST STAGE ENGINE		
2ND STAGE STRAP-ON	0.0	0.0
1ST STG.RECOV.DEVC.	0.0	0.0
2 PC.STRAPON SPARES		0.0
10 PC. CORE SPARES		20.15
SUB TOTAL DDT+E	2974.55	

TABLE 4.2-4. OPERATIONS COSTS

OPERATIONS				
PROPELLANTS/FLIGHT		0.08		
REPLENISHMENT SPARES/FLT		0.45		
OVERHAUL/FLT		0.14		
TRANSPORTATION/FLT		0.0		
TEST HARDWARE CONV.		29.96		
FAC/GSE REF.MTL./FLT, RATE	100.00	0.30		
FAC/GSE REF.MTL./FLT, RATE	220.00	0.14		
FAC/GSE REF.MTL./FLT, RATE	365.00	0.08		
FAC/GSE REF.MTL./FLT, RATE	445.00	0.07		
GS MANPOWER/YR AT RATE OF	100.	0.0		
GS MANPOWER/YR AT RATE OF	220.	0.0		
GS MANPOWER/YR AT RATE OF	365.	0.0		
GS MANPOWER/YR AT RATE OF	445.	0.0		
GSE+FACILITIES FOR RATE OF	100.	0.0		
GSE+FACILITIES FOR RATE OF	220.	0.0		
GSE+FACILITIES FOR RATE OF	365.	0.0		
GSE+FACILITIES FOR RATE OF	445.	0.0		
ADDIT.PROD FAC FOR RATE OF	100.00	0.0		
ADDIT.PROD FAC FOR RATE OF	220.00	0.0		
ADDIT.PROD FAC FOR RATE OF	365.00	0.0		
ADDIT.PROD FAC FOR RATE OF	445.00	0.0		
			SPC	TOTAL
COST PER FLIGHT AT RATE OF	100.00	0.98	0.05	1.03
COST PER FLIGHT AT RATE OF	220.00	0.81	0.04	0.86
COST PER FLIGHT AT RATE OF	365.00	0.76	0.04	0.80
COST PER FLIGHT AT RATE OF	445.00	0.75	0.04	0.78

OPERATIONS	
PROPELLANTS/FLIGHT	0.08
REPLENISHMENT SPARES/FLT	0.45
OVERHAUL/FLT	0.15
TRANSPORTATION/FLT	0.0
TEST HARDWARE CONV.	29.83

TABLE 4.2-5. ANNUAL FUNDING

CONFIGURATION B2 FLIGHTS= 445.0
B-2 ORBITER
R+D STG1 REC DEV STG 2. PROD STG 1 REC DEV STG 2
0.0 0.0 0.0 0.0 0.0 0.0
PROD LRN CURVE.STRAIGHT UNIT
STG 1= 0.950 REC DEV= 0.500 STG 2= 0.900

DDTE COSTS

YEAR	ORBITER	STAGE 1	STAGE 2	TEST OPS
1972.	0.4722E 02	0.0	0.0	0.1597E 01
1973.	0.2896E 03	0.0	0.0	0.8778E 01
1974.	0.5151E 03	0.0	0.0	0.1742E 02
1975.	0.6814E 03	0.0	0.0	0.2304E 02
1976.	0.6838E 03	0.0	0.0	0.2312E 02
1977.	0.5050E 03	0.0	0.0	0.1708E 02
1978.	0.1853E 03	0.0	0.0	0.6265E 01
1979.	0.0	0.0	0.0	0.0
1980.	0.0	0.0	0.0	0.0
1981.	0.0	0.0	0.0	0.0
1982.	0.0	0.0	0.0	0.0
1983.	0.0	0.0	0.0	0.0
1984.	0.0	0.0	0.0	0.0
1985.	0.0	0.0	0.0	0.0
1986.	0.0	0.0	0.0	0.0
1987.	0.0	0.0	0.0	0.0
TOTALS	0.2877E 04	0.0	0.0	0.9730E 02

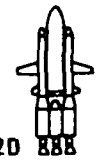
PRODUCTION COSTS

YEAR	ORBITER	STAGE 1	STAGE 2
1972.	0.0	0.0	0.0
1973.	0.0	0.0	0.0
1974.	0.0	0.0	0.0
1975.	0.0	0.0	0.0
1976.	0.0	0.0	0.0
1977.	0.2583E 02	0.0	0.0
1978.	0.1108E 03	0.0	0.0
1979.	0.1108E 03	0.0	0.0
1980.	0.1108E 03	0.0	0.0
1981.	0.1108E 03	0.0	0.0
1982.	0.0	0.0	0.0
1983.	0.0	0.0	0.0
1984.	0.0	0.0	0.0
1985.	0.0	0.0	0.0
1986.	0.0	0.0	0.0
1987.	0.0	0.0	0.0
TOTALS	0.4731E 03	0.0	0.0

OPERATING COSTS

YEAR	ORB REFRB	STG1 REFRB	PRPLNTS
1972.	0.0	0.0	0.0
1973.	0.0	0.0	0.0
1974.	0.0	0.0	0.0
1975.	0.0	0.0	0.0
1976.	0.0	0.0	0.0
1977.	0.0	0.0	0.0
1978.	0.5957E 01	0.0	0.8379E 00
1979.	0.8936E 01	0.0	0.1257E 01
1980.	0.1191E 02	0.0	0.1676E 01
1981.	0.1787E 02	0.0	0.2514E 01
1982.	0.2383E 02	0.0	0.3352E 01
1983.	0.2979E 02	0.0	0.4190E 01
1984.	0.3574E 02	0.0	0.5028E 01
1985.	0.4170E 02	0.0	0.5865E 01
1986.	0.4468E 02	0.0	0.6284E 01
1987.	0.4468E 02	0.0	0.6284E 01
TOTALS	0.2651E 03	0.0	0.3729E 02

TABLE 4.2-6. MID TERM COSTED POINT DESIGNS - CONCEPT B

	B-1A	B-2D 	B-2I
	S-1C 900 Fins (Interim) 100-Flights	Two Stage Pres. Fed 445 Flights	Two Stage 180" SRM 445 Flights
• DDT&E, $B	4.11	4.61	4.28
• Total Program, $B	7.44	9.90	11.57
• Cost/Flight, Operations and Expendables $M	—	10.3	14.7

4.2.1.1 Configuration B-1A

This configuration consists of a fully reusable orbiter and the S-1C Saturn as the boost vehicle. Modifications in the form of a mounting strongback for the orbiter and other structural components are required to complete the interface.

The S-1C basic booster and modification costs have been subjected to in-depth reviews, technical and cost analysis in the areas of rate production, improvement curves, and vehicle modifications. Modification analysis consisted of "grass roots" and parametric estimates of the strongback, forward skirt, fins and thrust structure.

Other B-1A Configuration Costs are presented in Tables 4.2-7, -8, -9 and Figure 4.2-1.

The B-1A configuration presents the lowest DDT&E cost of the three selected "B" configurations. Higher recurring hardware costs, however, result in higher total system cost for the 100 flight traffic model.

4.2.1.2 Configuration B-2D and B-2I

A series of five expendable pressure fed storable modules are combined to form the boost vehicle for the reusable orbiter in the B-2D configuration.

Three solid rocket motors are combined to form the boost vehicle for the fully recoverable orbiter in the B-2I configuration.

The technical and cost data for these configurations were subjected to extensive task force reviews during the period subsequent to the three-month review. The purpose of this review was to insure commonality in technical approaches and cost estimating methodology.

The B-2D and B-2I task force consisted of NASA, Grumman, and Boeing Engineering and Cost Personnel. The review covered all aspects of hardware

TABLE 4.2-7. B-1A SUMMARY WEIGHTS

	B-1A
Basic S-1C	4,948,000
Basic Modifications*	63,600
Strong Back*	91,000
BLOW	5,102,600
OLOW	745,400
GLOW	5,848,000
Propellant	4,575,000
S-1C Burnout Weight	1,273,000

* Includes 10% Growth

TABLE 4.2-8. B-1A COST SUMMARY 100 FLIGHTS - MIDTERM

DOLLARS IN MILLIONS

	Orbiter		Booster
DESIGN/DEVELOPMENT	1471.4		56.4
GROUND TEST HARDWARE	302.3		1.3
FLIGHT TEST HARDWARE	665.0		316.2
GROUND TEST OPS AND SUPT.	32.9		18.4
GROUND TEST FAC	12.0		------
MFG FACILITY	16.5		3.3
VEH SUPT EQUIP	109.7		------
VEHICLE TOTAL	2609.8		395.6
MAIN ENGINE	658.6		21.0
FLT/COM TEST OPS AND SUPT.		156.4	
FLT/COM TEST FAC/GSE		70.4	
SYST INT/MGT.		195.6	
TOTAL DDT&E		4107.4	
FLIGHT ARTICLES	------		2493.9
TEST VEH CONVERSION	74.8		------
PROD FAC ADDL.	------		53.9
SYS INT/MGMT	3.7		127.4
VEHICLE TOTAL	78.5		2675.2
PRODUCTION TOTAL		2753.7	
OPS AND SUPPORT		340.2	
MATERIALS		191.2	
OPS FAC/GSE (ADDL)		18.2	
SYSTEM INT/MGT		27.5	
OPS TOTAL		577.1	
GRAND TOTAL		7438.2	

TABLE 4.2-9. S-1C FIRST UNIT COST BREAKDOWN -MIDTERM

(DOLLARS IN MILLIONS)

Basic S-1C Stages	$28.0
MODIFICATIONS	
Forward Skirt	.3
Longitudinal Doublers	.1
Fins	4.4
Thrust Structure	1.0
Strongback	1.3
Instrumentation for flight test	0
Engine	9.0
Total S-1C	44.1

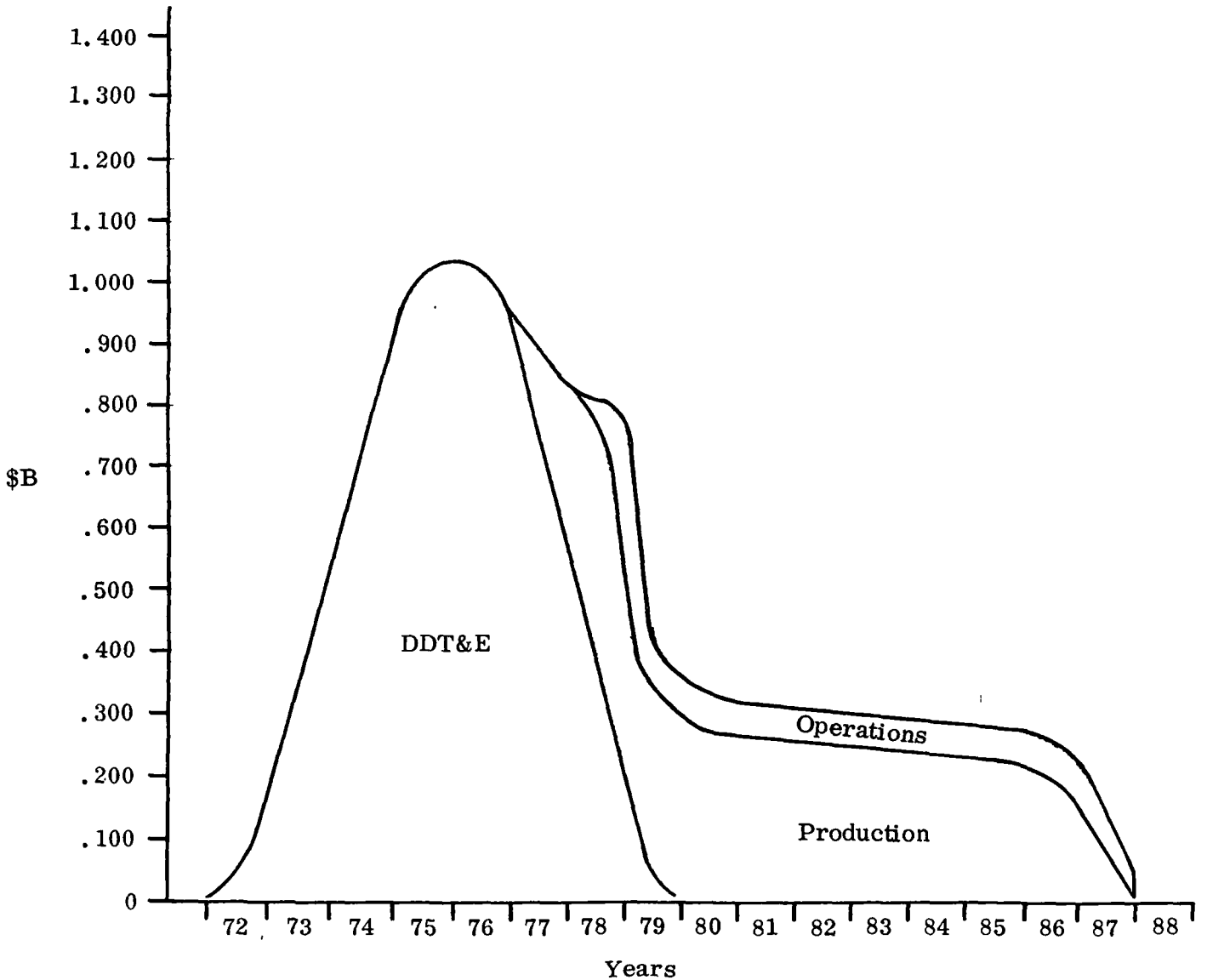


Figure 4.2-1. B-1A Annual Funding 100 Flights

recurring and operational costs. Updated cost resulting from these reviews are presented on the following tables and figures:

Table 4.2-10	B-2D Weight Statement
Table 4.2-11	B-2I Weight Statement
Table 4.2-12	B-2 Cost by Flight Rate
Table 4.2-13	B2 Cost Summary, 445 Flights
Figure 4.2-2	B-2D Annual Funding, 445 Flights
Figure 4.2-3	B-2I Annual Funding, 445 Flights
Table 4.2-14	First Unit Cost Summary

The B-2D configuration presents the lowest total system cost for each of the four traffic models. It has the highest DDT&E and operational costs of the three configurations. However, lower recurring hardware costs result in the lower total system costs.

4.2.2 Configuration Cost Comparison

This section presents the cost data developed to assist in the screening of the sixteen initial "B" concept configurations.

The technical characteristics and profile drawings of each configuration are shown in Figure 4.2-4 "Initial Study Matrix."

As noted in Volume II, Part I, six of the initial study configurations were eliminated from further consideration for technical reasons prior to the completion of the system costing activities. Consequently, no system costs were presented for these configurations at the six weeks review. Total system costs were developed and presented for each of the remaining ten configurations. This data is presented in Section 4.2.2.1 "Six-Week Comparisons."

TABLE 4.2-10. B-2D WEIGHT STATEMENT

		Orbiter	Stage 2	Stage 1
Body Structure			133,700	255,400
Induced Environment Protection			200	1,500
Main Propulsion			59,000	120,800
Power Conversion and Distribution			1,300	1,900
Instrumentation			100	100
Growth Allowance			9,800	18,900
Dry Weight	(Calc)		205,400	397,300
Residual Fluids			37,800	77,600
Expended Fluids/Inerts			10,300	20,800
Injection Weight	(Calc)		253,500	495,700
	(Target)		258,700	517,200
Over/Under Weight			(- 5,200)	(- 21,500)
Injection Propellant	(Target)		1,588,700	3,177,400
OLOW/BLOW	(Target)	745,400	1,847,400	3,694,600
Liftoff Weight	(Target)	6,287,400		
Mass Fraction	(Calc)		0.8624	0.8651
Mass Fraction	(Target)		0.860	0.860

TABLE 4.2-11. B-2I WEIGHT STATEMENT

		Orbiter	Stage 2	Stage 1
Body Structure			17,700	38,000
Induced Environment Protection			200	400
Main Propulsion			244,700	468,600
Power Conversion and Distribution			800	1,600
Instrumentation			100	200
Growth Allowance			5,300	10,200
Injection Weight	(Calc)		268,800	519,000
	(Target)		248,600	497,200
Over/Under Weight			(+ 20,200)	(+ 21,800)
Injection Propellant	(Target)		1,663,900	3,327,800
OLOW/BLOW	(Target)	745,400	1,912,500	3,825,000
Liftoff Weight	(Target)		6,482,900	
Mass Fraction	(Calc)		0.861	0.865
Mass Fraction	(Target)		0.870	0.870

TABLE 4.2-12. B-2 COST BY FLIGHT RATE

	B2D	B2I
• Peak Annual Funding	1,134	1,078
• RDT&E	4,613	4,276
• Total Program Costs		
• 445 Flights	9901	11,569
• 365 Flights	8954	10,190
• 220 Flights	7390	8,022
• 100 Flights	6231	6,215

TABLE 4.2-13. B2 COST SUMMARY 445 FLIGHTS

DOLLARS IN MILLIONS

	B2-D		B-2I	
	Orbiter	Booster	Orbiter	Booster
DESIGN/DEVELOPMENT	1471.4	245.0	1471.4	140.0
GROUND TEST HARDWARE	302.3	18.2	302.3	------
FLIGHT TEST VEHICLES	665.0	99.1	665.0	146.9
GROUND TEST OPS AND SUPT.	37.9	52.4	37.9	------
GROUND TEST FAC	12.0	20.5	12.0	------
MANUFACTURING FAC	16.8	15.6	16.8	4.0
VEHICLE SUPPORT EQUIP.	109.7	86.2	109.7	47.3
TOTAL VEHICLE	2615.1	537.0	2615.1	338.2
MAIN ENGINE	658.6	110.0	658.6	------
FLIGHT/COM TEST OPS AND SUPT.	187.8		157.5	
FLT/COM. TEST FAC/GSE	85.6		117.8	
SYS INT/MGMT	419.4		388.7	
TOTAL DDT&E	4613.5		4275.9	
FLIGHT ARTICLES	443.3	2385.9	443.3	5213.0
TEST VEHICLE CONV.	74.8	------	74.8	------
PRODUCTION FAC	------	101.9	------	162.5
SYS INT/MGMT	25.9	124.4	25.9	268.8
VEHICLE TOTAL	544.0	2612.2	544.0	5649.3
PRODUCTION TOTAL	3156.2		6188.3	

TABLE 4.2-13. B2 COST SUMMARY 445 FLIGHTS (Cont)

DOLLARS IN MILLIONS

	B2-D		B-2I	
	Orbiter	Booster	Orbiter	Booster
OPS & SUPPORT	954.5		458.4	
MATERIALS	1009.6		544.9	
OPS FAC/GSE (ADDL)	65.5		49.3	
SYSTEM INT/MGMT	101.4		52.6	
OPERATIONS TOTAL	2131.0		1105.2	
PROGRAM TOTAL	9900.7		11,569.4	

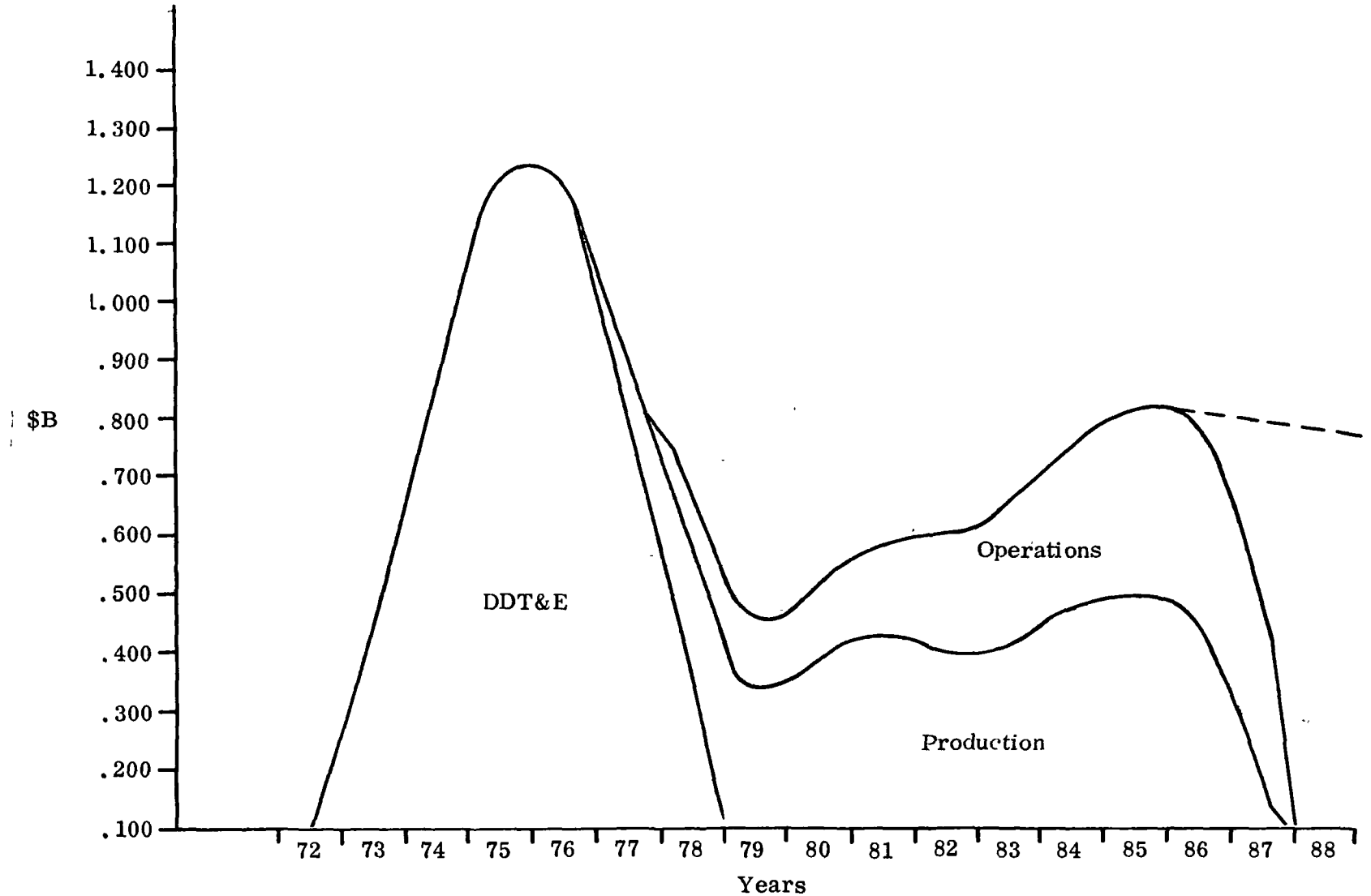


Figure 4.2-2. B-2D Annual Funding 445 Flights

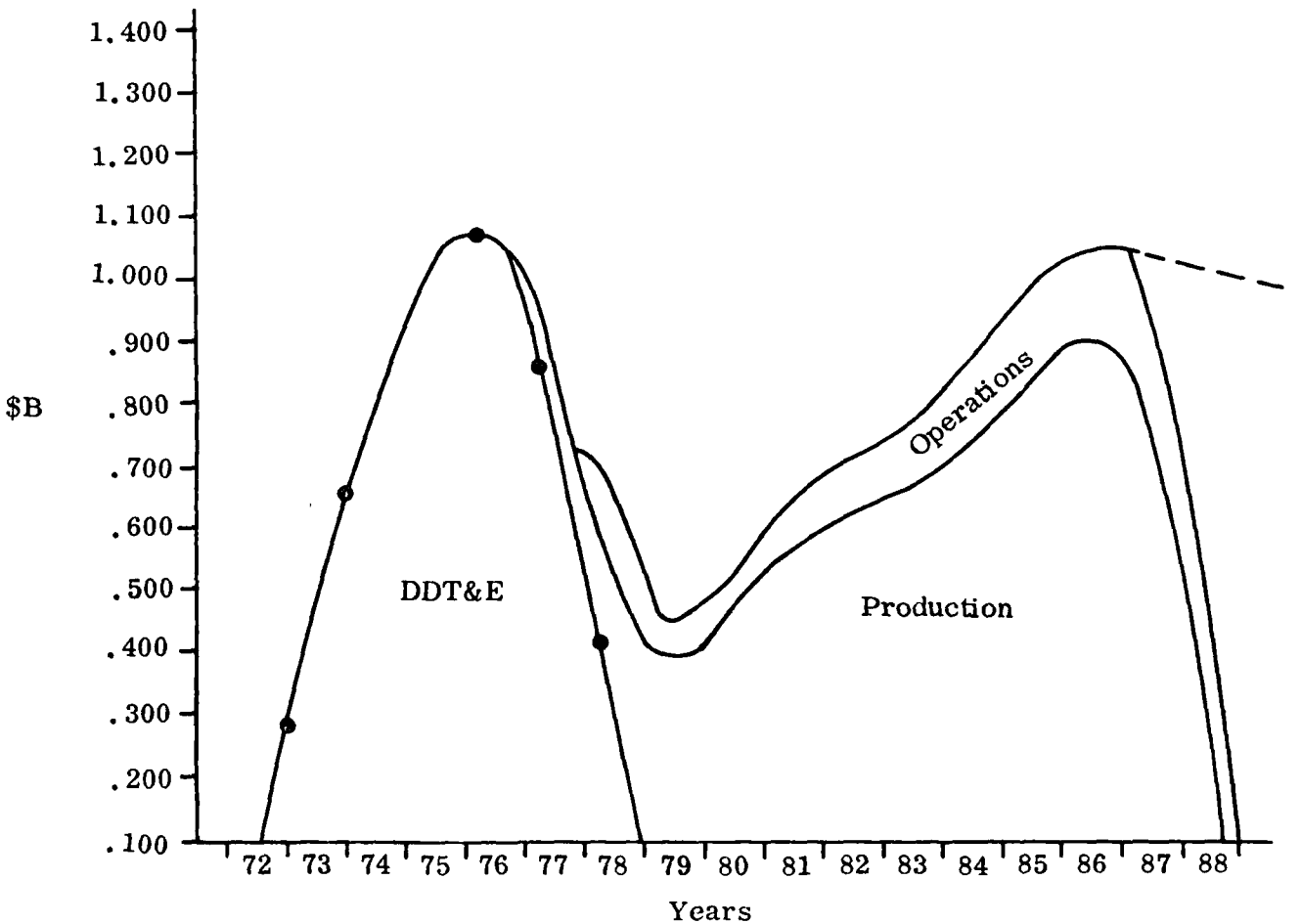


Figure 4.2-3. B-2I Annual Funding 445 Flights

TABLE 4.2-14. FIRST UNIT COST SUMMARY

	B-2D		B-2I	
	Orbiter	Booster**	Orbiter	Booster**
VEHICLE				
STRUCTURE	74.5	8.0	74.5	14.5
MAIN TANKS	25.6		25.6	
TPS	4.9		4.9	
MAIN PROP	7.4		7.4	
AIR BREATHERS				
OMS	3.8		3.8	
APS/TVC	6.6		6.6	
AVIONICS	64.0		64.0	
POWER	5.4		5.4	
ECLSS	1.8		1.8	
INTERSTAGE				
PROPELLANT	.08	1.1	.08	3.5
VEHICLE TOTAL	194.08	9.1	194.08	18.0
VEHICLE TOTAL W/O PROPELLANT	194.0	8.0	194.0	14.5
MAIN ENGINE	7.5	4.1	7.5	
TOTAL VEH & ENG DRY	201.5	12.1	201.5	14.5

COST IN MILLIONS

** B2D - TOTAL COST FOR 3 FIRST STAGE MODULES AND 2 SECOND STAGE MODULES

B2I - TOTAL COST FOR 3 SRM's

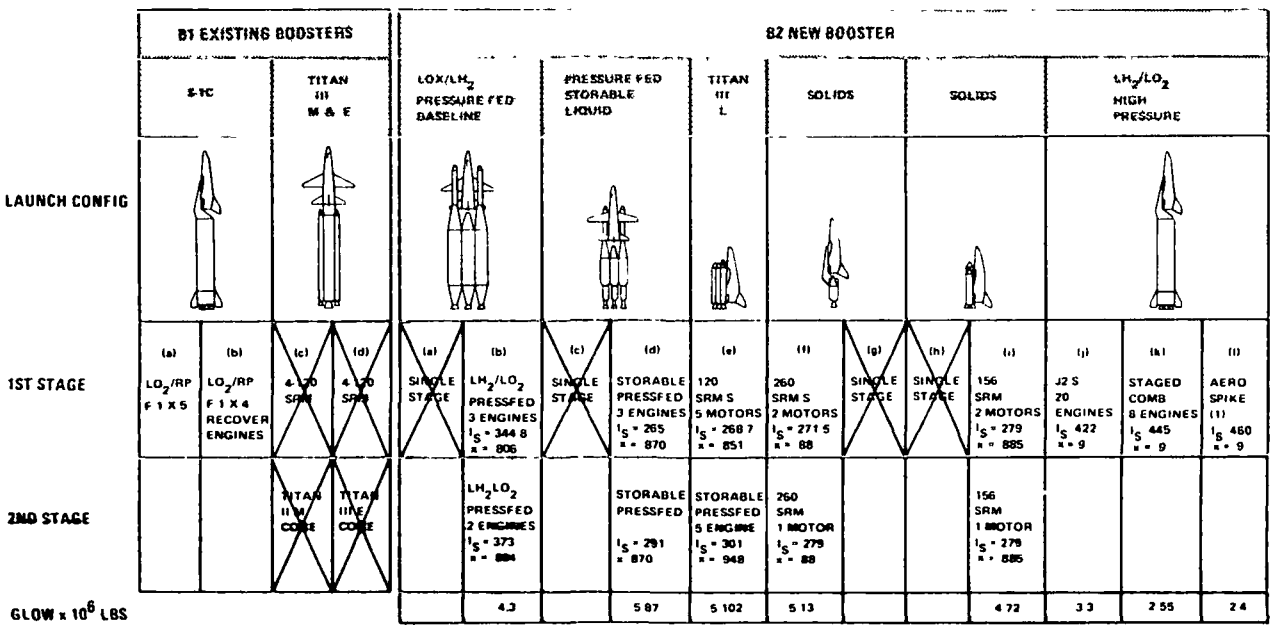


Figure 4.2-4. Initial Study Matrix

As a result of the six weeks review, three "B" concept configurations were selected for further study and refinement. In-depth technical and cost analysis were conducted on each of the configurations and supplier data was solicited to augment the "gross" cost estimating relationships (CERS) used in the six week screening. Section 4.2.2.2 contains a discussion of the "B" concept cost refinements conducted between the six-week and the three-month reviews. Updated cost summary and funding data for these configurations were presented at the three-month review. This data is presented in Section 4.2.2.3 "Three-Month Comparison."

Configurations B-1A, B-2D, and B-2I were retained for further consideration as a result of the three month review. A task force was formed to examine the cost and technical data on B-2D and B-2I to insure commonality in approach and methodology. As a result of these evaluations, certain refinements in the costs were accomplished to both configurations. These results, along with refinements in the B-1A configuration costs are presented in Sections 4.2.2.4 (B-1A), and 4.2.2.3 (B-2D, B-2I).

4.2.2.1 Six-Week Comparisons

The primary task for the first six-week review was to conduct a gross technical and system cost screening of 16 "B" concept configurations. Six of these configurations were eliminated from further consideration because of technical reasons prior to completion of the costing activities.

Technical characteristics for each of the configurations are presented on Table 4.2-15 and 4.2-16. These tables contain the basic weight data used to develop the hardware costs in the cost models.

Table 4.2-17 and Table 4.2-18 present total program costs for each of the remaining 10 configurations. Total program cost data for each of the four traffic models including non-recurring and recurring costs are also included.

Other screening factors, such as payload sensitivity, in addition to cost, were used to provide the criteria for the configuration selection. These factors are summarized on Figure 4.2-5.

TABLE 4.2-15. B-1A & B-1B TECHNICAL CHARACTERISTICS - 6 WEEKS

TRAJECTORY RESULTS

CUTOFF SEQUENCE OF 2-2-1**

	B1-BASELINE S-IC	B1 ALTERNATE S-IC RECOVER 4 ENGINES
Gross lift off weight, lb.	5,631,250	5,647,700
Interstage weight, lb.	50,000	50,000
Orbiter Config.	C21	C21
Orbiter Δ V (ideal), FPS	14,420	14,420
Orbiter lift off weight, lb.	624,300	624,300
Max. Q. PSF	758	699
Max. G	3.0	3.0
Engine drop cond. *		
Altitude, ft.		192,200
Velocity, FPS		4,600
Flight path angle		44
Orbiter weight at inj.		
Actual, lb.	235,400	233,900
Required, lb.	228,300	228,300

* Engine staging is made as early as possible to ease recovery.

** Performance is increased on S-IC baseline when 2-1-2 engine cutoff is used but G level is 3.3.

TABLE 4.2-16. B-2 POINT DESIGN CHARACTERISTICS MATRIX - 6 WEEKS

CHARACTERISTICS	$B2_B$	$B2_D$	$B2_E$	$B2_F$	$B2_I$	$B2_J$	$B2_K$	$B2_L$
ORBITER:	C2F	C2F	C2F	C2F	C2F	C2I	C2F	C2F
T/W	1.2	1.2	1.2	1.2	1.2	1.31	1.65	1.60
OLOW ~ LBS	575K	891K	500K	891K	765K	624.3K	623K	617K
ΔV ~ FPS	15K	18K	14K	18K	17K	14.42K	15K	15K
BOOSTER:								
1st STAGE								
ENGINE TYPE & NUMBER	PRESS FED x 3	PRESS FED x 3	120" SRM x 5	260" SRM x 2	156" SRM x 2	J-2S x 20	STAGED COMB x 8	AEROSPIKE x 1
$\frac{\text{THRUST}}{\text{ENGINE}} \times 10^6$ SEA LEVEL	1.720	2.67	1.3971	3.2	2.94	.2191	.400	3.06
VACUUM	2.400	2.82	1.5806	3.775	3.373	.2570	.462	3.72
I_s VACUUM ~ SECS	3.44.8	265	268.7	271.5	271.5	422	445	460
MIXTURE RATIO	6	2.4	---	---	---	5.5	6	6
NOZZLE EXPANSION RATIO	4.8	4.5	9.18	12	12	21.4	53	160
PROPELLANT ~ LBSx 10^6	2.25	2.86	2.96	2.46	2.24	2.2	1.75	1.6
λ'	.806	.870	.851	.88	.885	.9	.9	.9
2ND STAGE								
ENGINE TYPE & NUMBER	PRESS FED x 2	PRESS FED x 2	PUMP FED x 5	260" SRM x 1	156" SRM x 1	---	---	---
THRUST/ENG x 10^6 (VAC)	.900	1.55	.2615	2.85	3.470	---	---	---
I_s VACUUM ~ SECS	373	291	301	279	279	---	---	---
MIXTURE RATIO	6	2.4	1.93	---	---	---	---	---
NOZZLE EXPANSION RATIO	15	14	15	18	18	---	---	---
PROPELLANT ~ LBS x 10^6	.75	1.43	1.059	1.23	1.12	---	---	---
λ'	.804	.870	.948	.88	.890	---	---	---
ΔV IDEAL REQUIRED	31,500	31,200	31,480	30,700	30,700	30,700	30,700	30,700
GLOW T/W	1.2	1.25	1.4	1.25	1.25	1.25	1.25	1.25
GLOW	4.3	5.87	5.102	5.13	4.72	3.3	2.55	2.4

TABLE 4.2-17. B-1 TOTAL PROGRAM COST - 6 WEEKS

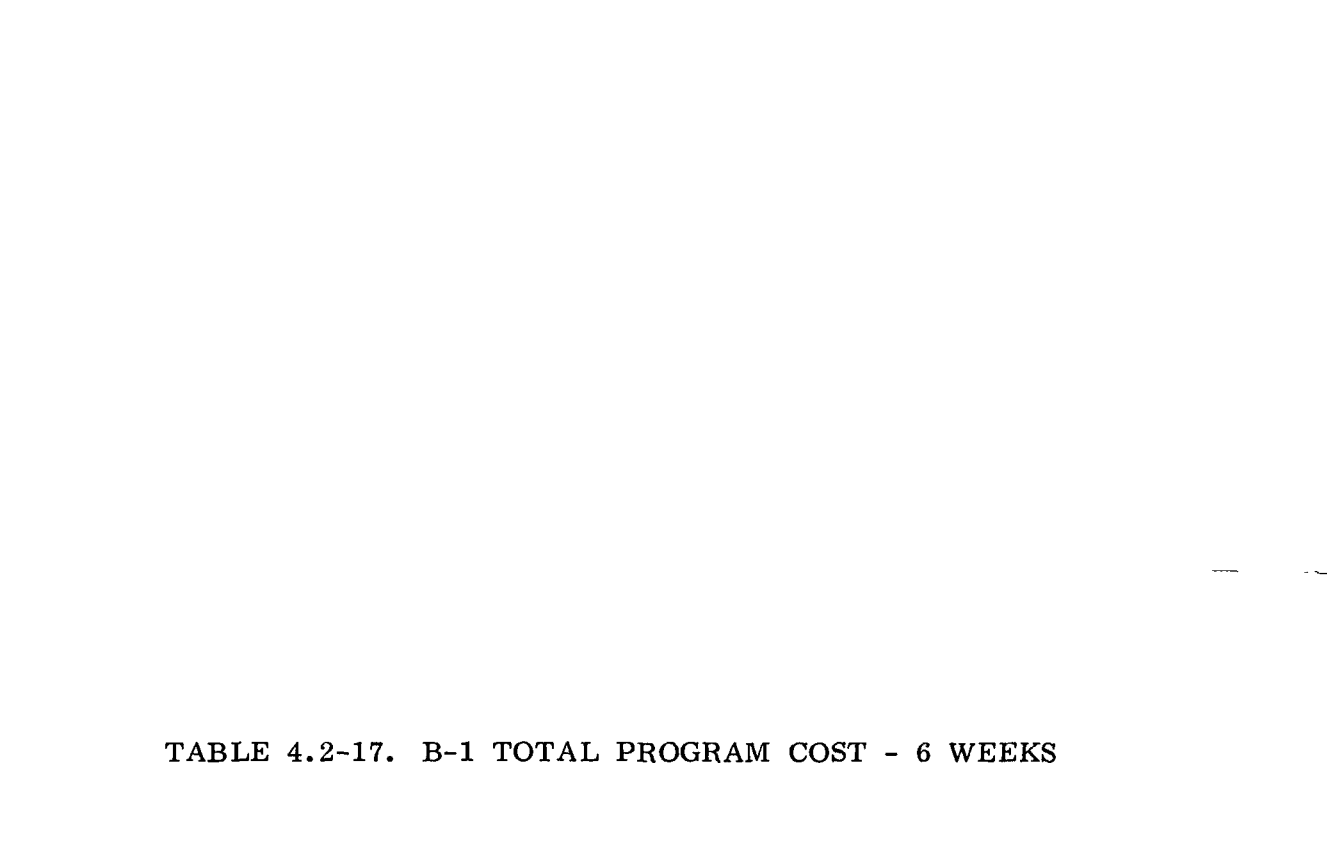
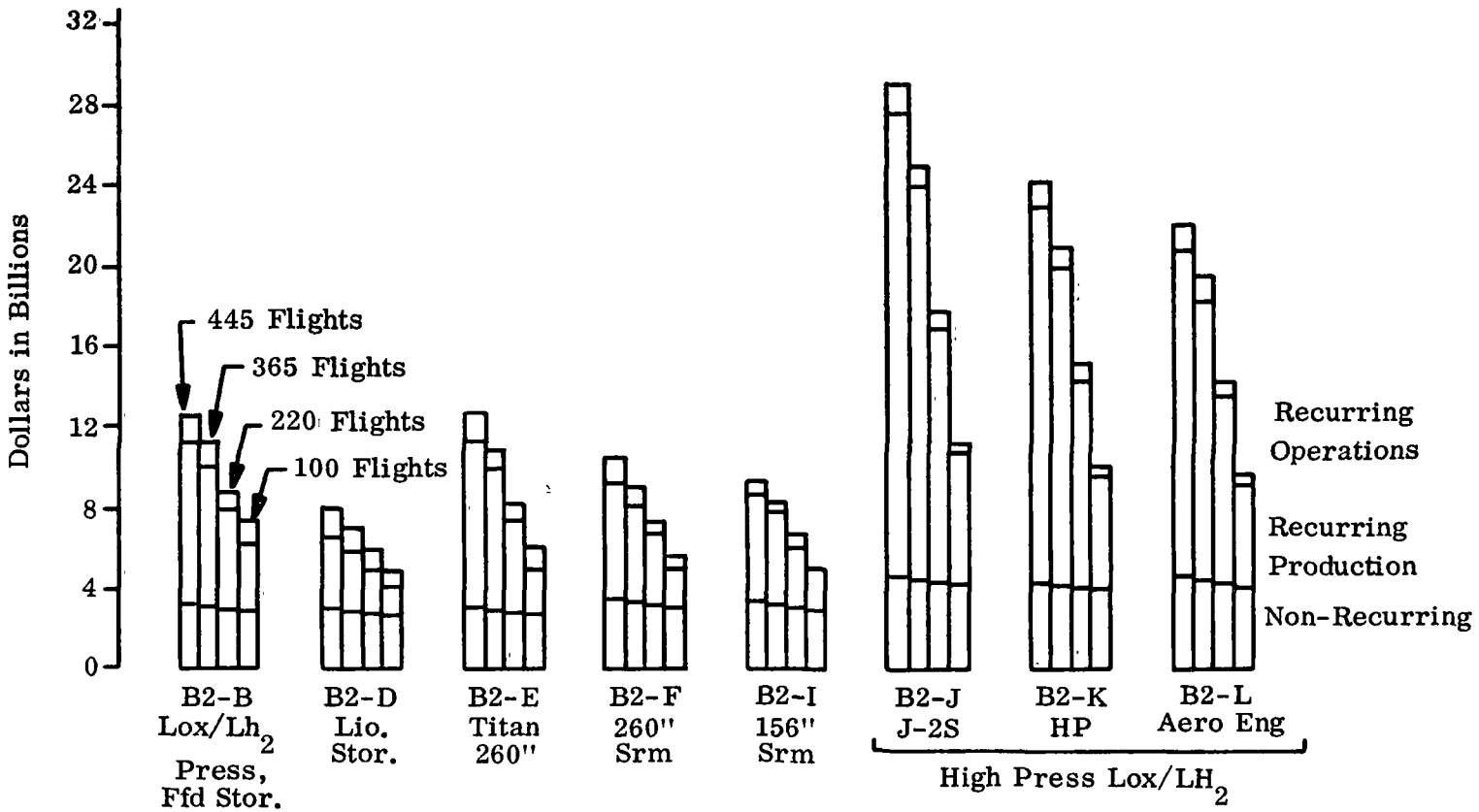


TABLE 4.2-18. B-2 TOTAL PROGRAM COST - 6 WEEKS



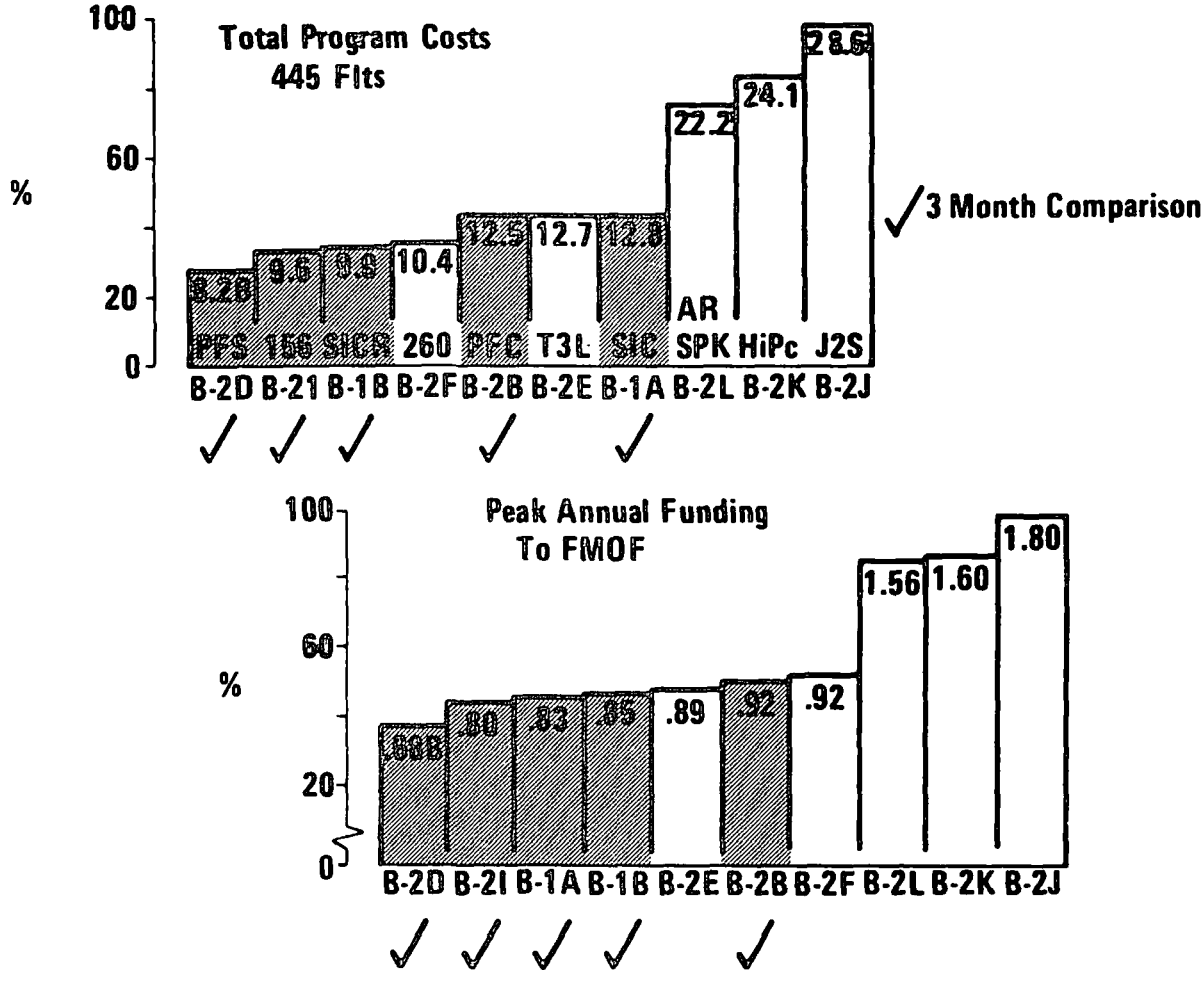


Figure 4.2-5. Six Weeks Results and Recommendations (Sheet 1)

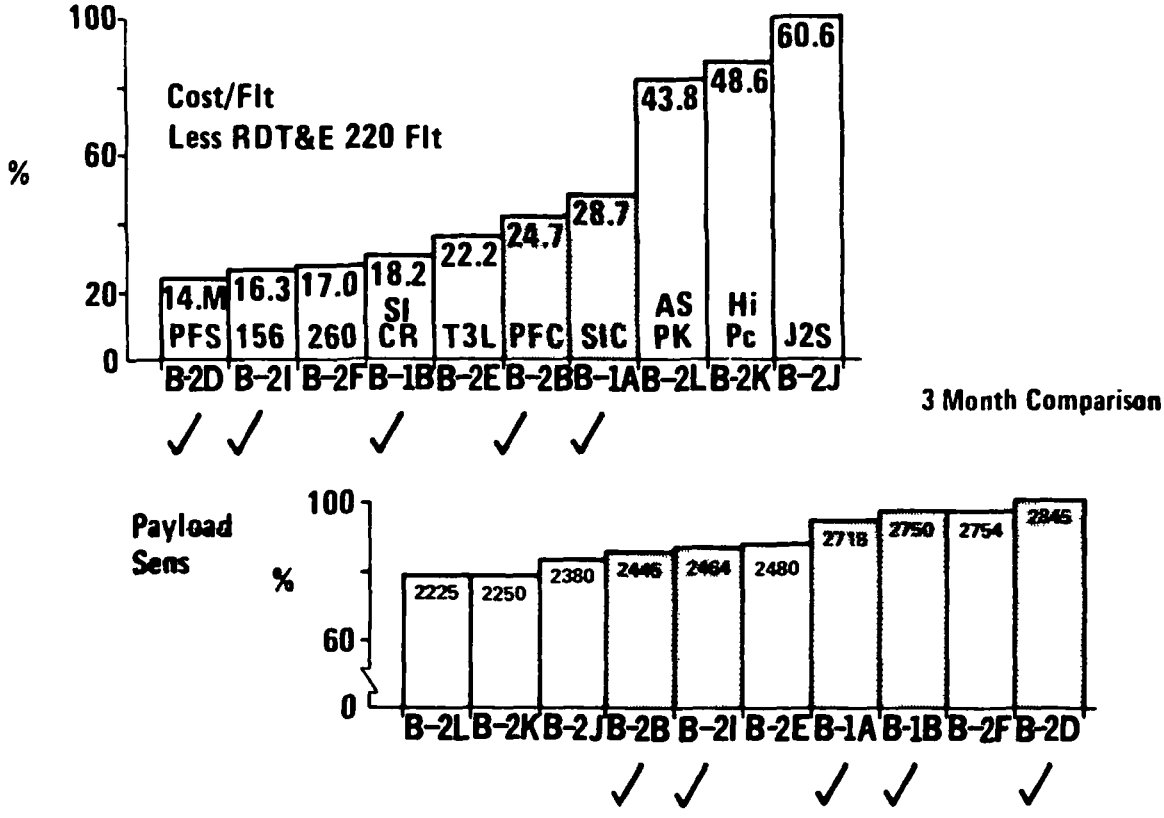


Figure 4.2-5. Six Weeks Results and Recommendations (Sheet 2)

4.2.2.2 Six Week/Three Month Cost Refinements

Four "B" concept configurations were retained for study and analysis after the six weeks review. The use of S-1C as a booster vehicle (Configuration B-1A) and the modification of this vehicle to allow for engine recovery (Configuration B-1b) were two of the four configurations. Configurations B-2d and B-2i were also retained for further study.

One of the primary tasks during the second six weeks period was the refinement of the costs for the selected configurations. Additional technical definition of the subsystems was to be accomplished and the "grass" cost estimating, relationships (CERS) used for the six week screening, were to be replaced or verified with more detailed estimates.

During the second six weeks, each of the Configurations (B-1A, B-1B, B-2d, and B-2i) were the subject of technical and cost analysis to accomplish the desired refinement.

The hardware costs for Configuration B-1A and B-1B were developed by The Boeing Company's Saturn Program Personnel at the Michoud facility in New Orleans, Louisiana. Non-recurring and recurring costs were developed from Saturn historical data with updating to account for escalation, Saturn production line stoppage, and space shuttle requirements. Operation costs were derived from Boeing's extensive knowledge of the Saturn vehicle operations and maintenance requirements.

The cost and technical analysis conducted on Configuration B-2d utilize as a basis Boeing Company studies on low cost launch vehicle concepts conducted since the early sixties. In 1968, Boeing spearheaded a program with a group of specialized personnel to study the feasibility of using HY 140 steel to fabricate a low cost launch vehicle. This Company sponsored activity was titled, The Cost Optimized Launch Vehicle (COLV) Program. In early 1969, Boeing was awarded an Air Force contract to conduct further study on this concept. The results of this effort are documented as the "Minimum Cost Design/Space Launch Vehicle" Air Force Contract F04701-69-C-0402.

Statistical projections of this data were required to properly scale it to the sizing requirements of the B-2D modules. Historical tankage and structure trends of cost with increasing weight were utilized to determine the appropriate slopes for projection of the data base. DDT&E and operational costs were similarly derived using the data base developed in the contracted studies. Updated supplier data, for items such as pressure fed engines, were also included in the development of the system costs.

Since the B-2i configuration consists solely of three solid rocket motors as the boost vehicle, it was felt necessary to solicit rocket motor suppliers' technical and cost inputs to assist in the configuration evaluation. Three major rocket motor manufacturers responded to Boeing-provided data packages with technical data and rough order of magnitude (ROM) cost estimates. In addition, the Aerospace Corporation was contacted and provided data on Titan launch vehicle solid rocket motors and SRM cost estimating relationships. This data was utilized to select and cost the B-2i SRM motor configurations presented in the Three Month Review.

Studies were undertaken in conjunction with the solid rocket motor suppliers to evaluate manufacturing, handling and shipping problems associated with the fabrication and assembly of large solid rocket motors. The studies provided cost estimates of facilities, ground equipment, and shipping.

4.2.2.3 Three-Month Comparisons (B-1a, B-2d and B-2i)

The cost data presented at the three-month review is included in this section. These costs are the result of the cost refinements and analyses conducted during the second six-weeks study period. Prior to the three-month review, the B-1b configuration was withheld from further costing activities pending the selection of a final "B" concept configuration.

Tables 4.2-19 and 4.2-20 summarize the technical characteristics of the configurations costed at the three month review.

TABLE 4.2-19. B-1 SUMMARY WEIGHTS - 3 MONTHS

	B1A	B1B
Basic S-1C	4,948,000	4,948,000
Basic Modicications*	34,000	34,000
Recovery Mods*		32,000
Strong Back*	91,000	91,000
BLOW	5,073,000	5,105,000
OLOW	745,000	745,000
GLOW	5,818,400	5,850,000
Staged Weight		216,000
Propellant	4,575,000	4,575,000
S-1C Burnout Weight	1,243,400	1,059,400

*Includes 10% Growth

TABLE 4.2-20. B-2 TECHNICAL CHARACTERISTICS SUMMARY - 3 MONTHS

CHARACTERISTICS	B-2D	B-2I
Orbiter		
T/W (Initial)	1.25	1.25
OLOW ~ Lb	745,400	745,400
ΔV ~ fps	15,870	15,870
Booster		
First Stage		
Engine Type and Number	Pressure-Fed Storable-3	180-Inch Solids-2
Thrust/Engine (S.L.) ~ 10^6 Lb	2.62	4.05
I_S (Vac) ~ Seconds (S.L.)	229.5	229
Mixture Ratio	2.4	–
Nozzle Expansion Ratio	4.5	12
Propellant Wt ~ Lb	3,177,385	3,327,700
λ' CALC	0.8651	0.865
λ' TGT	0.860	0.870
Second Stage		
Engine Type and Number	Pressure-Fed Storable-2	180-Inch Solid-1
Thrust/Engine (Vac) ~ 10^6 Lb	1.56	4.94
I_S (Vac) ~ Seconds	291	279
Mixture Ratio	2.4	–
Nozzle Expansion Ratio	14	18
Propellant Wt ~ Lb	1,588,693	1,663,850
λ' CALC	0.8624	0.861
λ' TGT	0.860	0.870
ΔV Ideal Total Required	30,755	30,990
Liftoff T/W	1 25	1.25
GLOW ~ Lb	6,287,351	6,482,812

The total system costs presented at the three month review for configurations B-1a, B-2d and B-2i are shown on Table 4.2-21. DDT&E and cost per flight data are also included in this table.

The total B-2d and B-2i systems costs for 445 flights are shown by WBS element and program phase on Table 4.2-22.

4.2.2.4 B-1a Cost Refinement

The B-1a configuration booster hardware costs have been reviewed and examined in-depth by Boeing Saturn program personnel. Analysis of startup costs to restore the Michoud facility to full production have been conducted. The areas of rate production and corresponding improvement curves have been examined for the space shuttle traffic models.

Technical analysis of the modifications required on the Saturn vehicle to accomodate the reusable orbiter have been reflected in hardware costs through a series of "grass roots" and parametric cost estimates. Manufacturing hours and material costs were developed for each modification. Unit modification cost estimates were calculated using the current labor and overhead rates.

The Saturn hardware and modification costs have been subject to a series of management reviews to insure completeness and accuracy.

4.2.2.5 3-Month to Midterm Cost Refinement

The entire pressure fed storable booster concept (Configuration B-2d) has been studied in greater depth for the Mid Term estimate. Each subsystem cost was compared with the Minimum Cost Design Space Launch Vehicle MCD/SLV Study Contract performed in New Orleans, Louisiana for the Air Force (SAMSO). This comparison has been conducted in conjunction with the B-2d - B-2i task force activities to insure commonality in estimating approach and methodology.

As a result of these analyses and discussions the following refinements in the B-2d total systems costs have been accomplished.

TABLE 4.2-21. B EXPENDABLE BOOSTER (C-4 ORBITER) - 3 MONTHS

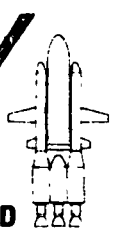
	B-1A	B-2D 	B-2I
	S-1C 900 Fins (Interim) 100-Flights	Two Stage Pres. Fed 445 Flights	Two Stage 180" SRM 445 Flights
• DDT&E, $B	4.12	4.66	4.39
• Total Program, $B	7.10	10.34	12.70
• Cost/Flight			
- Amortized Production Hardware, $M	29.3	11.4	16.8
- No Reusable Production Hardware $M	28.8	10.4	15.8
• Payload Sensitivity (Lbs/% W_I)		2278	2264
• Cost Sensitivity			
($M/% W_i)		49	65
($M/% Isp)		484	567

TABLE 4.2-22. B-2 COST SUMMARY, 445 FLIGHTS - 3 MONTHS

(Dollars in Millions)

	B-2D	B-2I
RDT&E - Total	(4,663.1)	(4,385.3)
Orbiter	2,146.5	2.146.5
Booster	298.5	140.0
Test Vehicles	1,077.2	1,129.2
Test & Operations Support	380.7	300.4
Test Facilities/GSE	305.2	251.3
Manufacturing Facilities	31.2	19.2
Systems Management & Integration	423.9	398.7
Production - Total	(3,178.4)	(6,981.3)
Orbiter	452.8	452.8
Booster	2,411.2	5,969.1
Test Vehicle Conversion	74.0	74.0
Production Facilities	89.0	153.0
Systems Management & Integration	151.3	332.4
Operations - Total	(2,502.6)	(1,332.1)
Operations & Support	954.4	459.2
Materials	1,363,4	760.2
Operations Facilities/GSE (Add'l)	65.6	49.3
Systems Management & Integration	119.2	83.4
Total Program Cost	10,344.1	12,698.7

Non-recurring cost estimates were increased by approximately $50 million as a result of a reevaluation of slope of the trend line used in the non-recurring cost estimating relationship (CER).

Recurring cost estimates were increased for the propellant delivery subsystem, integration and assembly. Reductions in the recurring costs were made in the first stage engine costs.

In all cases these changes were necessary to agree with refined cost data obtained from the final results of the MCD/SLV study contract. This data was reevaluated for developing the cost estimating relationships. These cost changes were all minor in nature and did not change the total vehicle cost.

A reduction in the vehicle total cost did result from a reduction in the propellant cost. Propellant costs were reduced based on the latest revision to the Department of Defense Federal Supply Catalog - C 9100 1L and ML dated 24 July 1970.

The fuel cost of UDMH was reduced from $.64/lb to $.48/lb. The original cost of UDMH was obtained from AFLC CMAL Number 69.7 Fuels Division; Standard Prices for Missile Fuels Management Category, dated 1 October 1969. This reduction in propellant costs resulted in lower overall vehicle cost of $200,000 per flight.

The refinement in the B-2i configuration costs, since the Three Month Review, have been primarily in the determination of the first unit recurring costs for solid rocket motors. Task force analysis of the configuration and rocket motor manufacturers' presentations have provided the bulk of data for the refinement of the solid rocket motor costs.

Three solid rocket motor manufacturers provided the task force with subsystem breakdowns of their first unit production costs estimates and discussed their procurement, manufacturing and assembly practices. Discussions were also held on improvement curves, potential cost reductions in the selection of case materials and comparative evaluations of segmented versus monolithic motor construction.

The Aerospace Corporation was also asked to provide an overall evaluation of the cost and performance values quoted by the SRM manufacturers.

In attempting to compare the costs of the major SRM subsystems, various differences in the costing procedures by the manufacturers had to be reconciled to obtain "apples and apples" comparisons. Thus allocations of various costs of assembly, integration, administrative expense, etc. were assigned to the major subsystems on a proportional basis.

Cost estimates were then made to arrive at a composite value for each Rocket Motor subsystem, considering the manufacturers' differences and the B-2i configuration requirements. Thus a synthesized first unit production value was developed by adding the subsystem cost estimates.

Several of the solid rocket motor manufacturers revised their cost estimates based on clarifications and further definition of the B-2i configuration requirements received during the task force discussions.

As a parallel study to the task force analysis, the revised SRM manufacturers' estimates and the Aerospace Corporation CER were statistically examined for a "least squares" trend line of a cost/weight relationship. This trend line indicated less than a 5% variance from the synthesized cost estimate established by examining each SRM subsystem. The Three Month solid rocket motor cost estimating relationship was revised to reflect the trend line and the synthesized estimate. The revised CER has been used to calculate the B-2i cost estimates presented at the Midterm Review.

4.2.3 NASA Cost Form

This section includes completed NASA cost estimate forms "A" and "B" (Ref. MF003M) for configurations B-1a, B-2d and B-2i. Separate sets of forms ("A" and "D") are submitted for non-recurring (DDT&E), recurring (production), and recurring (operations) costs for each of the three configurations.

The forms display total cost and fiscal year distributions for

B-1a	DDT&E	Tables 4.2-23 & -24
	Production	4.2-25 & -26
	Operations	4.2-27 & -28
B-2d	DDT&E	Tables 4.2-29 & -30
	Production	4.2-31 & -32
	Operations	4.2-33 & -34
B-2i	DDT&E	Tables 4.2-35 & -36
	Production	4.2-37 & -38
	Operations	4.2-39 & -40

TABLE 4.2-23. COST ESTIMATE DATA FORM A - B-1a (DDT&E)

Date _____

X Non-Recurring (DDT&E)

__ Recurring (Production)

__ Recurring (Operations)

Page ____ of ____

VEHICLE CONFIGURATION B1A

NO. OF FLTS. 100

WBS IDENTIFICATION NO.	WBS ITEM NAME	WBS ITEM COST	NUMBER OF UNITS
	Orbiter	2615	3
	Booster	398	7 sets
	Main Engine	659	--
	Flight Test	239	--
	Program Management	196	--

TABLE 4.2-24. COST ESTIMATE DATA FORM D - B-1a (DDT&E)

Date _____

x Non-Recurring (DDT&E)

__ Recurring (Production)

__ Recurring (Operations)

Page ____ of ____

VEHICLE CONFIGURATION B-1a

NO. OF FLTS. 100

PROJECT WBS ITEMS	FY 72	FY 73	FY 74	FY 75	FY 76	FY 77	FY 78	FY 79
Orbiter	8.5	173	463	663	663	463	173	8.5
Booster	.90	19	54	85	98	85	50	6.1
Main Engine	2.15	43.6	116.6	167	167.3	116.6	43.6	2.15
Flight Test	.05	2.60	13.0	32.1	54.6	68.9	57.6	10.15
Program Management	14	28	28	28	28	28	28	14

TABLE 4.2-25. COST ESTIMATE DATA FORM A - B-1a (PRODUCTION)

Date _____

_____ Non-Recurring (DDT&E)

Page ____ of ____

x____ Recurring (Production)

_____ Recurring (Operations)

VEHICLE CONFIGURATION B1A

NO. OF FLTS. 100

WBS IDENTIFICATION NO.	WBS ITEM NAME	WBS ITEM COST	NUMBER OF UNITS
	Orbiter	75	0
	Booster	2548	100 Sets
	Main Engine	--	---
	Flight Test	--	---
	Program Management	131	---

TABLE 4.2-26. COST ESTIMATE DATA FORM D - B-1a (PRODUCTION)

Date _____

____ Non-Recurring (DDT&E)

Page ___ of _____

x___ Recurring (Production)

____ Recurring (Operations)

VEHICLE CONFIGURATION B1A

NO. OF FLTS. 100

PROJECT WBS ITEMS	FY 78	FY 79	FY 80	FY 81	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	FY 88
Orbiter	38	37									
Booster	202	316	280	261	248	239	232	225	221	217	107
Main Engine	-	-	-	-	-	-	-	-	-	-	-
Flight Test	-	-	-	-	-	-	-	-	-	-	-
Program Management	12	18	14	13	12	12	12	12	11	10	5

TABLE 4.2-27. COST ESTIMATE DATA FORM A - B-1a (OPERATIONS)

Date _____

_____ Non-Recurring (DDT&E)

Page ____ of ____

_____ Recurring (Production)

__x__ Recurring (Operations)

VEHICLE CONFIGURATION B1A

NO. OF FLTS. 100

WBS IDENTIFICATION NO.	WBS ITEM NAME	WBS ITEM COST	NUMBER OF UNITS
	Operations	549	
	Program Management	28	

TABLE 4.2-28. COST ESTIMATE DATA FORM D - B-1a (OPERATIONS)

Date _____

____ Non-Recurring (DDT&E)

____ Recurring (Production)

x ___ Recurring (Operations)

Page _____ of _____

VEHICLE CONFIGURATION B1A

NO. OF FLTS. 100

PROJECT WBS ITEMS	FY 78	FY 79	FY 80	FY 81	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	FY 88
Operations	49	65	54	53	52	51	50	50	50	50	25
Program Management	2	4	4	4	3	2	2	2	2	2	1

TABLE 4.2-29. COST ESTIMATE DATA FORM A - B-2D (DDT&E)

Date _____

x Non-Recurring (DDT&E)

Page ____ of ____

____ Recurring (Production)

____ Recurring (Operations)

VEHICLE CONFIGURATION B2D

NO. OF FLTS. 445

WBS IDENTIFICATION NO.	WBS ITEM NAME	WBS ITEM COST	NUMBER OF UNITS
	Orbiter	2615.0	3
	Booster	537.0	8
	Main Engine	769.0	
	Flight Test	273.4	
	Program Management	419.4	

TABLE 4.2-30. COST ESTIMATE DATA FORM D - B2D (DDT&E)

Date _____

x Non-Recurring (DDT&E)

_____ Recurring (Production)

_____ Recurring (Operations)

Page _____ of _____

VEHICLE CONFIGURATION B2D

NO. OF FLIGHTS 445

PROJECT WBS ITEMS	FY 72	73	74	75	76	77	78	79
Orbiter	8.54	173.15	462.5	663.0	663.7	462.5	173	8.54
Booster	1.0	26.0	72.0	115.0	132.0	115.0	67.0	9.0
Main Engine	2.59	51.0	136.0	194.0	195.0	136.5	51.3	2.59
Flight Test	.25	6.0	22.0	44.0	64.0	72.0	56.0	9.15
Program Management	31.5	59.4	59.4	59.4	59.4	59.4	59.4	31.5

TABLE 4.2-31. COST ESTIMATE DATA FORM A - B2D (PRODUCTION)

Date _____

_____ Non-Recurring (DDT&E)

Page ___ of ___

__x__ Recurring (Production)

_____ Recurring (Operations)

VEHICLE CONFIGURATION B2D

NO. OF FLTS. 445

WBS IDENTIFICATION NO.	WBS ITEM NAME	WBS ITEM COST	NUMBER OF UNITS
	Orbiter	500.8	2
	Booster	2488.0	445
	Main Engine	17.0	4
	Flight Test	---*---	
	Program Management	150.0	

*INCLUDED IN BOOSTER AND ORBITER COSTS

TABLE 4.2-32. COST ESTIMATE DATA FORM D - B2D (PRODUCTION)

Date _____

_____ Non-Recurring (DDT&E) Page ___ of ___

__x__ Recurring (Production)

_____ Recurring (Operations)

VEHICLE CONFIGURATION B2D NO. OF FLTS. 445

PROJECT WBS ITEMS	FY 77	78	79	80	81	82	83	84	85	86	87	88
Orbiter	33	95.3	106.5	106	106.5	53.3						
Booster	-	42	94	106	154	220	247	295	339	363	367	179
Main Engine		2	4	5	4	2	-					
Flight Test*		-	-	-	-	-						
Program Management	1	4	12.3	15.5	16.5	16.5	16.5	16.5	16.5	16.5	13.3	4.9

TABLE 4.2-33. COST ESTIMATE DATA FORM A - B2D (OPERATIONS)

Date _____

_____ Non-Recurring (DDT&E)

_____ Recurring (Production)

__x__ Recurring (Operations)

Page ____ of ____

VEHICLE CONFIGURATION B2D

NO. OF FLTS. 445

WBS IDENTIFICATION NO.	WBS ITEM NAME	WBS ITEM COST	NUMBER OF UNITS
	Operations	2030	
	Program Management	101	

TABLE 4.2-34. COST ESTIMATE DATA FORM D - B2D (OPERATIONS)

Date _____

_____ Non-Recurring (DDT&E)

_____ Recurring (Production)

__x__ Recurring (Operations)

Page ____ of ____

VEHICLE CONFIGURATION B2D

NO. OF FLTS. 445

PROJECT WBS ITEMS	FY 78	79	80	81	82	83	84	85	86	87	88
Operations	30	90	110	130	170	200	240	270	310	300	170
Program Management	3	6	11	11	11	11	11	11	11	11	4

TABLE 4.2-35. COST ESTIMATE DATA FORM A - B2I (DDT&E)

Date 12-11-70

x Non-Recurring (DDT&E)

Page 1 of 1

_____ Recurring (Production)

_____ Recurring (Operations)

VEHICLE CONFIGURATION B2i

NO. OF FLTS. 445

WBS IDENTIFICATION NO.	WBS ITEM NAME	WBS ITEM COST	NUMBER OF UNITS
	Orbiter	2615.0	3
	Booster	338.0	8
	Main Engine	659.0	-
	Flight Test	275.0	-
	Program Management	389.0	-

TABLE 4.2-36. COST ESTIMATE DATA FORM D - B2I (DDT&E)

Date 12-11-70

x Non-Recurring (DDT&E)

Page 1 of 1

_____ Recurring (Production)

_____ Recurring (Operations)

VEHICLE CONFIGURATION B2i

NO. OF FLTS. 445

PROJECT WBS ITEMS	FY 72	FY 73	FY 74	FY 75	FY 76	FY 77	FY 78	FY 79
Orbiter	8.54	173.2	462.5	663.2	663.3	462.6	173.1	8.54
Booster	.76	16.1	46.0	72.3	82.9	72.3	42.1	5.50
Main Engine	2.15	43.64	116.6	167.1	167.2	116.6	43.6	2.15
Flight Test	.30	7.35	24.60	46.33	64.78	70.53	52.49	8.59
Program Management	28.3	54.4	55.4	55.4	56.4	55.4	55.4	28.3

TABLE 4.2-37. COST ESTIMATE DATA FORM A - B2I (PRODUCTION)

Date 12-11-70

_____ Non-Recurring (DDT&E)

Page 1 of 1

__x__ Recurring (Production)

_____ Recurring (Operations)

VEHICLE CONFIGURATION B2i

NO. OF FLTS. 445

WBS IDENTIFICATION NO.	WBS ITEM NAME	WBS ITEM COST	NUMBER OF UNITS
	Orbiter	500.8	2
	Booster	5375.5	445 Sets
	Main Engine	17.0	-
	Flight Test	*	-
	Program Management	295.0	-

*INCLUDED IN BOOSTER & ORBITER COSTS

TABLE 4.2-38. COST ESTIMATE DATA FORM D - B2I (PRODUCTION)

Date 12-11-70

_____ Non-Recurring (DDT&E)

Page 1 of 1

_x_ Recurring (Production)

_____ Recurring (Operations)

VEHICLE CONFIGURATION B2i

NO. OF FLTS. 445

PROJECT WBS ITEMS	FY 77	78	FY 79	80	FY 81	82	FY 83	84	FY 85	86	FY 87	88
Orbiter	33.0	95.3	106.5	106.0	106.5	53.5						
Booster		76.0	161.0	206.0	397.2	525.3	541.0	645.0	748.0	824.0	847.0	405.0
Main Engine		3.0	4.0	4.0	4.0	2.0						
Flight Test *												
Program Management	4.0	18.3	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	14.3

*INCLUDED IN BOOSTER & ORBITER COSTS

TABLE 4.2-39. COST ESTIMATE DATA FORM A - B2I (OPERATIONS)

Date 12-11-70

Page 1 of 1

_____ Non-Recurring (DDT&E)

_____ Recurring (Production)

x Recurring (Operations)

VEHICLE CONFIGURATION B2i

NO. OF FLTS. 445

WBS IDENTIFICATION NO.	WBS ITEM NAME	WBS ITEM COST	NUMBER OF UNITS
	Operations	1052.0	
	Program Management	53.0	

TABLE 4.2-40. COST ESTIMATE DATA FORM D - B2I (OPERATIONS)

Date 12-11-70

_____ Non-Recurring (DDT&E)

Page 1 of 1

_____ Recurring (Production)

_X_ Recurring (Operations)

VEHICLE CONFIGURATION B2i

NO. OF FLTS. 445

PROJECT WBS ITEMS	FY 78	FY 79	FY 80	FY 81	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	FY 88
Operations	31.0	50.0	50.0	67.0	86.0	101.0	121.0	145.0	160.0	163.0	78.0
Program Management	1.0	3.0	4.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	3.0

4.3 Concept C

Configuration C-4 is a 2 stage fully reusable vehicle with a payload of 25000 lb. As a result of the 3 month review, this point design was selected for further analysis and costing efforts. The results of the latest cost analysis and the vehicle design inputs are summarized in this section.

4.3.1 Midterm Cost Analysis - Configuration C-4

Included in this section are program cost summaries at different flight rates (Tables 4.3-1 through 4.3-14), detailed cost breakdowns of DDT&E and average production unit costs including costs per flight (Table 4.3-3) and annual funding including annual cash flow discounted at 5% and 10% (Tables 4.3-5 and -10).

A detailed weight breakdown for configuration C-4 is presented in Tables 4.3-1 and 4.3-6.

TABLE 4.3-1. WEIGHT SUMMARY - BOOSTER

WING	55000.
FLAP	0.0
TAIL (CT.)	7450.
TAIL (OBD)	21323.
BODY	140302.
TPS	50052.
LANDING GEAR	17217.
RECOV. & DOCK.	0.0
ROCKET	47334.
AIR BREATHER	15215.
INSTALLATION	23200.
TANKS	0.0
ORIENT. CTL.	3009.
AVIONICS	6017.
FIXED WTS.	7230.
CONTG.	41764.
DRY WEIGHT	459822.
DELTA TARGET	0.0
TARGET DRY WT.	459822.
CREW	400.
M.S. & RES.	22957.
LANDED WT.	483400.
FLY HOME	4272.
MAX. CARGO WT.	500-10.
RES. & RES.	21323.
RCS PROP.	0.0
SEP. SYS.	0.0
INJECTION WT.	5-7341.
INJECT. PROP.	240243.
GLOW	2350000.
GLOW	306.300.

TABLE 4.3-2. CONFIGURATION C4 BOOSTER COST MODEL INPUTS

C4 BOOSTER T/W= 1.25

MACH SEA LEVEL	0.27	FLIGHT RATE NO.1.	100.00	TI PERCENT OF AMPR	0.05
MACH ALTITUDE	1.00	FLIGHT RATE NO.2.	220.00	GS MANPWR/YR. RATE 1	19.13
PROD.RATE/MO. MIN=1	1.00	FLIGHT RATE NO.3.	365.00	GS MANPWR/YR. RATE 2	22.20
YEAR OF FIRST FLIGHT	1976.00	FLIGHT RATE NO.4.	445.00	GS MANPWR/YR. RATE 3	30.59
DOLLAR CONVERSION YR	1970.00	GSE+FAC. RATE 1	0.0	GS MANPWR/YR. RATE 4	34.91
		GSE+FAC. RATE 2	30.90	G+A PERCENT	0.10
		GSE+FAC. RATE 3	30.90	EQUIV.TEST ARTICLES	3.70
		GSE+FAC. RATE 4	30.90	TEST HARDWARE CONV.	10.00
APU DEV.	9.30	APU PROD.	2.30	ELECTRONIC WEIGHT	2900.00
OOMS DEV.	0.0	OOMS PROD.	0.0	HOURS/FLIGHT	10.00
AVIONICS DEV.	539.00	AVIONICS PROD.	61.00	NO.OF RCS ENGINES	40.00
ELEC. PWR. CRYO DEV.	10.00	ELEC. PWR. CRYO PROD	0.90	TEST OPERATIONS	169.40
ECS DEV.	14.00	ECS PROD.	0.70	TEST FACILITIES	278.90
BAT/FUEL CELLS DEV.	1.70	BAT/FUEL CELLS PROD.	0.44	NO OF TEST FLIGHTS	7.00
AIRBREATHERS DEV.	100.00	AIRBREATHERS PROD.	4.50	CRYO TANK DEV.	80.00
TPS DEV.	112.00	FUEL SYS WT-FRCT.DEV	0.93	ADDIT.PROD FAC RATE1	0.0
TRANSPORTATION DEV.	0.03	FUEL SYS FACTOR DEV.	15.00	ADDIT.PROD FAC RATE2	0.0
TRANSPORTATION PROD.	0.0	FUEL SYS FACTOR PROD	6.45	ADDIT.PROD FAC RATE3	0.0
TANK INSUL. DEV.	0.25	FUEL SYS T/BASE LINE	4800000.00	ADDIT.PROD FAC RATE4	0.0
NO.OF TEST CONVERTS	2.00	FUEL SYS WT-FRCT.PRO	0.83	NON REC MFG FAC	25.00
ENGINE FACT. DEV.	0.0	RCS FACTOR DEV.	55.00	TEST ART.. 1ST STAGE	0.0
TANKAGE FACT. DEV.	1.53	RCS FACTOR 1 PROD.	4.01	TEST ART.. 2ND STAGE	0.0
TANKAGE FACT. PROD.	2.30	RCS FACTOR 2 PROD.	2.48		
TPS CARBON	0.0	FLTS/TPS CARBON	1.00		
TPS RIGID INS.	0.0	FLTS/TPS RIGID INS.	1.00		
TPS COLUMBIUM	0.16	FLTS/TPS COLUMBIUM	25.00		
TPS HAYNES	0.0	FLTS/TPS HAYNES	1.00		
TPS THORIUM	0.0	FLTS/TPS THORIUM	1.00		
TPS TITANIUM	0.0	FLTS/TPS TITANIUM	1.00		
TPS RENE	0.64	FLTS/TPS RENE	35.00		
TPS ABLATIVE	0.0	FLTS/TPS ABLATIVE	1.00		
T/W STAGING	1.25	STRUCT. DENSITY	1.60	STRAPON TOT.ROCK. WT	0.0
TOGW CORE	734000.00	FRAME WT. EMPTY	304406.00	STRAPON FUEL WT.	0.0
TOGW COMBINED	3664000.00	TOGW MINUS SPACE SYS	372325.00	STRAPON TOT.THRUST	0.0
DELTA V 1ST STAGE	15950.00	FUEL WT OF CORE	2402459.00	STRAPON TANK WT.FULL	0.0
AMPR	291456.00	THRUST/ENGINE	459750.00	STRAPON TANK WT EMP.	0.0
DRY WEIGHT	45622.00	NO. OF ENGINES	11.53		
RCS WEIGHT	9609.00	TANK INSUL. AREA	10982.00		
TPS AREA	16203.00	INJECTION WEIGHT	527541.00		

TABLE 4.3-3. COST SUMMARY - MIDTERM (COMPUTER FORMAT)

C4 BOOSTER T/W= 1.25

COSTS IN MILLION DOLLARS

	DDT+E	AV. UNIT PROD
AIRFRAME	551.50	123.15
TANK INSULATION	0.25	2.42
TPS	112.00	9.67
FUEL SYSTEM	36.71	16.09
TANKAGE	153.73	37.63
ROCKET ENGINES	0.0	42.81
AIR BREATHING ENG.	100.00	4.50
APU	9.30	2.30
ON ORBIT MANEUV.SYS	0.0	0.0
AVIONICS	339.00	61.00
ELECT. PWR. CRYO.	10.00	0.90
BAT/FUEL CELLS	1.72	0.44
ENV. CONTROL SYS.	14.00	0.70
REACTION CONT. SYS.	74.19	11.69
TOT SUBSYSTEMS	448.19	77.03
TEST OPERATIONS	159.40	
TEST FL PROPELLANTS	2.74	
TEST AIRFRAME	455.67	
TEST TPS	32.08	
TEST FUEL SYSTEM	59.54	
TEST TANKAGE	139.24	
TEST TANK INSUL.	8.54	
TEST ENGINES	175.06	
TEST REPL. HARDWARE	9.83	
TEST 1ST STRAPON	0.0	
TEST 2ND STRAPON	0.0	
TEST SUBSYSTEMS	248.01	
TOT TEST HARDWARE	1161.07	
SUB TOTAL	2735.98	312.31
1ST STAGE STRAP-ON	0.0	0.0
1ST STAGE ENGINE		
2ND STAGE STRAP-ON	0.0	0.0
1ST STG.RECOV.DEVC.	0.0	0.0
2 PC.STRAPON SPARES		0.0
10 PC. CORE SPARES		31.23
SUB TOTAL DDT+E	2735.98	
TEST FAC/GSE	278.90	
MFG FAC NON REC.	25.00	
TRANSPORT. NON REC.	0.63	
SUB TOTAL NON REC	3040.51	
10 PC SYS INT + MGT	304.05	

TABLE 4.3-3. COST SUMMARY - MIDTERM (COMPUTER FORMAT) (Cont)

TOTAL NON REC.	3344.57			
OPERATIONS				
PROPELLANTS/FLIGHT		0.39		
REPLENISHMENT SPARES/FLT		0.41		
OVERHAUL/FLT		0.38		
TRANSPORTATION/FLT		0.0		
TEST HARDWARE CONV.		37.34		
FAC/GSE REF.MTL./FLT. RATE	100.00	1.52		
FAC/GSE REF.MTL./FLT. RATE	220.00	0.76		
FAC/GSE REF.MTL./FLT. RATE	365.00	0.46		
FAC/GSE REF.MTL./FLT. RATE	445.00	0.38		
GS MANPOWER/YR AT RATE OF	100.	19.13		
GS MANPOWER/YR AT RATE OF	220.	22.20		
GS MANPOWER/YR AT RATE OF	365.	30.59		
GS MANPOWER/YR AT RATE OF	445.	34.91		
GSE+FACILITIES FOR RATE OF	100.	0.0		
GSE+FACILITIES FOR RATE OF	220.	30.90		
GSE+FACILITIES FOR RATE OF	365.	30.90		
GSE+FACILITIES FOR RATE OF	445.	30.90		
ADDIT.PROD FAC FOR RATE OF	100.00	0.0		
ADDIT.PROD FAC FOR RATE OF	220.00	0.0		
ADDIT.PROD FAC FOR RATE OF	365.00	0.0		
ADDIT.PROD FAC FOR RATE OF	445.00	0.0		
			SPC	TOTAL
COST PER FLIGHT AT RATE OF	100.00	4.61	0.23	4.84
COST PER FLIGHT AT RATE OF	220.00	2.95	0.15	3.10
COST PER FLIGHT AT RATE OF	365.00	2.48	0.12	2.60
COST PER FLIGHT AT RATE OF	445.00	2.34	0.12	2.46

Table 4.3-4. Cost Spread - Midterm (Computer Format) - Booster

CONFIGURATION ... FLIGHTS= 445.0
C4 BOOSTER
R+D STG1 REC DEV STG 2, PROD STG 1 REC DEV STG 2
0.0 0.0 0.0 0.0 0.0 0.0
PROD LRN CURVE, STRAIGHT UNIT
STG 1= 0.950 REC DEV= 0.900 STG 2= 0.900

DDTE COSTS

YEAR	ORBITER	STAGE 1	STAGE 2	TEST OPS	GSE+FAC	TOTAL + 10 PC
1972.	0.4212E 02	0.0	0.0	0.2780E 01	0.4997E 01	0.5488E 02
1973.	0.2715E 03	0.0	0.0	0.1528E 02	0.2747E 02	0.3017E 03
1974.	0.4594E 03	0.0	0.0	0.3032E 02	0.5451E 02	0.5987E 03
1975.	0.6078E 03	0.0	0.0	0.4012E 02	0.7212E 02	0.7921E 03
1976.	0.6100E 03	0.0	0.0	0.4026E 02	0.7237E 02	0.7948E 03
1977.	0.4505E 03	0.0	0.0	0.2973E 02	0.5345E 02	0.5870E 03
1978.	0.1653E 03	0.0	0.0	0.1091E 02	0.1961E 02	0.2154E 03
1979.	0.0	0.0	0.0	0.0	0.0	0.0
1980.	0.0	0.0	0.0	0.0	0.0	0.0
1981.	0.0	0.0	0.0	0.0	0.0	0.0
1982.	0.0	0.0	0.0	0.0	0.0	0.0
1983.	0.0	0.0	0.0	0.0	0.0	0.0
1984.	0.0	0.0	0.0	0.0	0.0	0.0
1985.	0.0	0.0	0.0	0.0	0.0	0.0
1986.	0.0	0.0	0.0	0.0	0.0	0.0
1987.	0.0	0.0	0.0	0.0	0.0	0.0
TOTALS	0.2567E 04	0.0	0.0	0.1694E 03	0.3045E 03	0.3345E 04

PRODUCTION COSTS

YEAR	ORBITER	STAGE 1	STAGE 2	TOTAL + 5 PC
1972.	0.0	0.0	0.0	0.0
1973.	0.0	0.0	0.0	0.0
1974.	0.0	0.0	0.0	0.0
1975.	0.0	0.0	0.0	0.0
1976.	0.0	0.0	0.0	0.0
1977.	0.3734E 02	0.0	0.0	0.3921E 02
1978.	0.1718E 03	0.0	0.0	0.1804E 03
1979.	0.1718E 03	0.0	0.0	0.1804E 03
1980.	0.1718E 03	0.0	0.0	0.1804E 03
1981.	0.1718E 03	0.0	0.0	0.1804E 03
1982.	0.1718E 03	0.0	0.0	0.1804E 03
1983.	0.1718E 03	0.0	0.0	0.1804E 03
1984.	0.0	0.0	0.0	0.0
1985.	0.0	0.0	0.0	0.0
1986.	0.0	0.0	0.0	0.0
1987.	0.0	0.0	0.0	0.0
TOTALS	0.1068E 04	0.0	0.0	0.1121E 04

OPERATING COSTS

YEAR	FAC/GSE/MPH	ORB REFRB	STG1 REFRB	PRPLNTS	TOTAL+SPC	GRND TOTL
1972.	0.0	0.0	0.0	0.0	0.0	0.5488E 02
1973.	0.0	0.0	0.0	0.0	0.0	0.3017E 03
1974.	0.0	0.0	0.0	0.0	0.0	0.5987E 03
1975.	0.0	0.0	0.0	0.0	0.0	0.7921E 03
1976.	0.0	0.0	0.0	0.0	0.0	0.7948E 03
1977.	0.0	0.0	0.0	0.0	0.0	0.6262E 03
1978.	0.5474E 02	0.7898E 01	0.0	0.3916E 01	0.6988E 02	0.4656E 03
1979.	0.5474E 02	0.1185E 02	0.0	0.5874E 01	0.7608E 02	0.2564E 03
1980.	0.5474E 02	0.1580E 02	0.0	0.7832E 01	0.8229E 02	0.2626E 03
1981.	0.5474E 02	0.2369E 02	0.0	0.1175E 02	0.9469E 02	0.2751E 03
1982.	0.5474E 02	0.3159E 02	0.0	0.1566E 02	0.1071E 03	0.2879E 03
1983.	0.5474E 02	0.3949E 02	0.0	0.1958E 02	0.1195E 03	0.2999E 03
1984.	0.5474E 02	0.4739E 02	0.0	0.2350E 02	0.1319E 03	0.1319E 03
1985.	0.5474E 02	0.5529E 02	0.0	0.2741E 02	0.1443E 03	0.1443E 03
1986.	0.5474E 02	0.5924E 02	0.0	0.2937E 02	0.1505E 03	0.1505E 03
1987.	0.5474E 02	0.5924E 02	0.0	0.2937E 02	0.1505E 03	0.1505E 03
TOTALS	0.5474E 03	0.3515E 03	0.0	0.1743E 03	0.1127E 04	0.5593E 04

TABLE 4.3-5. DISCOUNTED COST SPREAD - MIDTERM
(COMPUTER FORMAT) BOOSTER

INTEREST RATES & TOTAL PRESENT VALUES
BASE YEAR= 1970.

2.00	0.4696E 04	4.00	0.3977E 04	6.00	0.3394E 04	8.00	0.2917E 04
10.00	0.2524E 04	12.00	0.2157E 04	14.00	0.1923E 04	16.00	0.1692E 04
18.00	0.1495E 04	20.00	0.1327E 04				

DISCOUNTED CASH FLOW AT 10.000 -

YEAR	ANN. COST	CUM.	DISCOUNT	CUM.
1972.	0.5488E 02	0.5488E 02	0.4124E 02	0.4124E 02
1973.	0.3017E 03	0.3566E 03	0.2061E 03	0.2473E 03
1974.	0.5987E 03	0.9553E 03	0.3718E 03	0.6191E 03
1975.	0.7921E 03	0.1747E 04	0.4471E 03	0.1066E 04
1976.	0.7948E 03	0.2542E 04	0.4079E 03	0.1474E 04
1977.	0.6262E 03	0.3168E 04	0.2921E 03	0.1766E 04
1978.	0.4656E 03	0.3634E 04	0.1975E 03	0.1964E 04
1979.	0.2564E 03	0.3890E 04	0.9887E 02	0.2063E 04
1980.	0.2626E 03	0.4153E 04	0.9206E 02	0.2155E 04
1981.	0.2751E 03	0.4428E 04	0.8764E 02	0.2242E 04
1982.	0.2875E 03	0.4716E 04	0.8327E 02	0.2325E 04
1983.	0.2999E 03	0.5015E 04	0.7896E 02	0.2404E 04
1984.	0.1319E 03	0.5147E 04	0.3158E 02	0.2436E 04
1985.	0.1443E 03	0.5292E 04	0.3141E 02	0.2467E 04
1986.	0.1505E 03	0.5442E 04	0.2978E 02	0.2497E 04
1987.	0.1505E 03	0.5593E 04	0.2707E 02	0.2524E 04

TOTAL= 0.2524E 04

INTEREST RATES & TOTAL PRESENT VALUES
BASE YEAR= 1970.

2.00	0.4696E 04	4.00	0.3977E 04	6.00	0.3394E 04	8.00	0.2917E 04
10.00	0.2524E 04	12.00	0.2157E 04	14.00	0.1923E 04	16.00	0.1692E 04
18.00	0.1495E 04	20.00	0.1327E 04				

DISCOUNTED CASH FLOW AT 5.000 -

YEAR	ANN. COST	CUM.	DISCOUNT	CUM.
1972.	0.5488E 02	0.5488E 02	0.4741E 02	0.4741E 02
1973.	0.3017E 03	0.3566E 03	0.2482E 03	0.2956E 03
1974.	0.5987E 03	0.9553E 03	0.4691E 03	0.7647E 03
1975.	0.7921E 03	0.1747E 04	0.5910E 03	0.1356E 04
1976.	0.7948E 03	0.2542E 04	0.5649E 03	0.1921E 04
1977.	0.6262E 03	0.3168E 04	0.4238E 03	0.2345E 04
1978.	0.4656E 03	0.3634E 04	0.3001E 03	0.2645E 04
1979.	0.2564E 03	0.3890E 04	0.1574E 03	0.2802E 04
1980.	0.2626E 03	0.4153E 04	0.1536E 03	0.2956E 04
1981.	0.2751E 03	0.4428E 04	0.1532E 03	0.3109E 04
1982.	0.2875E 03	0.4716E 04	0.1524E 03	0.3261E 04
1983.	0.2999E 03	0.5015E 04	0.1515E 03	0.3413E 04
1984.	0.1319E 03	0.5147E 04	0.6345E 02	0.3476E 04
1985.	0.1443E 03	0.5292E 04	0.6611E 02	0.3542E 04
1986.	0.1505E 03	0.5442E 04	0.6567E 02	0.3608E 04
1987.	0.1505E 03	0.5593E 04	0.6254E 02	0.3670E 04

TOTAL= 0.3670E 04

TABLE 4.3-6. WEIGHT SUMMARY - ORBITER

WING	26000.
FLAP	0.0
TAIL (CTL)	4277.
TAIL (OBD)	2000.
BODY	62700.
TPS	30177.
LANDING GEAR	7550.
ROCKET	10478.
AIR BREATHER	0.0
INSTALLATION	6001.
TANKS	2027.
ORIENT. CTL.	5734.
HYDRAULICS	5353.
FIXED WTS.	7022.
CONTIN.	10073.
DRY WEIGHT	185000.
DELTA TARGET	0.0
TARGET DRY WT.	185000.
CREW	400.
RES. & MES.	1994.
CARGO	25000.
LANDED WT.	212394.
FLY BACK	0.0
MAX. CRUISE WT.	212394.
RES. & MES.	3750.
OMS PROP.	21571.
RCS PROP.	4246.
INJECTION WT.	240173.
INJECT. PROP.	40523.
LOW	754000.
GLOW	0.0

TABLE 4.3-7. CONFIGURATION C4 ORBITER COST MODEL INPUTS

C4 ORBITER T/W= 1.25

MACH SEA LEVEL	0.27	FLIGHT RATE NO.1.	100.00	TI PERCENT OF AMPR	0.63
MACH ALTITUDE	1.00	FLIGHT RATE NO.2.	220.00	GS MANPWR/YR. RATE 1	0.0
PROD.RATE/MO. MIN=1	1.00	FLIGHT RATE NO.3.	365.00	GS MANPWR/YR. RATE 2	0.0
YEAR OF FIRST FLIGHT	1976.00	FLIGHT RATE NO.4.	445.00	GS MANPWR/YR. RATE 3	0.0
DOLLAR CONVERSION YR	1970.00	GSE+FAC. RATE 1	0.0	GS MANPWR/YR. RATE 4	0.0
		GSE+FAC. RATE 2	0.0	G+A PERCENT	0.10
		GSE+FAC. RATE 3	0.0	EQUIV.TEST ARTICLES	4.80
		GSE+FAC. RATE 4	0.0	TEST HARDWARE CONV.	10.00
APU DEV.	14.60	APU PROD.	1.60	ELECTRONIC WEIGHT	2547.00
ODMS DEV.	111.00	ODMS PROD.	3.78	HOURS/FLIGHT	124.00
AVIONICS DEV.	520.00	AVIONICS PROD.	54.00	NO.OF RCS ENGINES	22.00
ELEC. PWR. CRYO DEV.	10.80	ELEC. PWR. CRYO PROD	1.70	TEST OPERATIONS	97.30
ECS DEV.	60.00	ECS PROD.	1.80	TEST FACILITIES	44.70
BAT/FUEL CELLS DEV.	25.50	BAT/FUEL CELLS PROD.	2.08	NO OF TEST FLIGHTS	3.00
AIRBREATHERS DEV.	0.0	AIRBREATHERS PROD.	0.0	CRYO TANK DEV.	80.00
TPS DEV.	120.00	FUEL SYS WT-FRCT.DEV	0.96	ADDIT.PROD FAC RATE1	0.0
TRANSPORTATION DEV.	0.0	FUEL SYS FACTOR DEV.	13.00	ADDIT.PROD FAC RATE2	0.0
TRANSPORTATION PROD.	0.0	FUEL SYS FACTOR PROD	2.90	ADDIT.PROD FAC RATE3	0.0
TANK INSUL. DEV.	1.55	FUEL SYS T/BASE LINE	800000.00	ADDIT.PROD FAC RATE4	0.0
NO.OF TEST CONVERTS	2.00	FUEL SYS WT-FRCT.PRC	0.86	NON REC MFG FAC	16.00
ENGINE FACT. DEV.	2.10	RCS FACTOR DEV.	220.00	TEST APT., 1ST STAGE	0.0
TANKAGE FACT. DEV.	1.53	RCS FACTOR 1 PROD.	4.20	TEST APT., 2ND STAGE	0.0
TANKAGE FACT. PROD.	3.10	RCS FACTOR 2 PROD.	2.70		
TPS CARBON	0.0	FLTS/TPS CARBON	1.00		
TPS RIGID INS.	0.0	FLTS/TPS RIGID INS.	1.00		
TPS COLUMBIUM	0.17	FLTS/TPS COLUMBIUM	10.00		
TPS HAYNES	0.56	FLTS/TPS HAYNES	100.00		
TPS THORIUM	0.0	FLTS/TPS THORIUM	1.00		
TPS TITANIUM	0.23	FLTS/TPS TITANIUM	100.00		
TPS RENE	0.0	FLTS/TPS RENE	1.00		
TPS ABLATIVE	0.04	FLTS/TPS ABLATIVE	1.00		
T/W STAGING	1.25	STRUCT. DENSITY	1.69	STRAPON TOT.ROCK. WT	0.0
TOGW CORE	734000.00	FRAME WT. EMPTY	130241.00	STRAPON FUEL WT.	0.0
TOGW COMBINED	734000.00	TOGW MINUS SPACE SYS	171237.00	STRAPON TOT.THRUST	0.0
DELTA V 1ST STAGE	15950.00	FUEL WT OF CORE	507395.00	STRAPON TANK WT.FULL	0.0
AMPR	117088.00	THRUST/ENGINE	458750.00	STRAPON TANK WT EMP.	0.0
DRY WEIGHT	185000.00	NO. OF ENGINES	2.00		
RCS WEIGHT	5795.00	TANK INSUL. AREA	5724.00		
TPS AREA	6200.00	INJECTION WEIGHT	248175.00		

TABLE 4.3-8. COST SUMMARY - MIDTERM (COMPUTER FORMAT) ORBITER

C4 ORBITER T/W= 1.25

COSTS IN MILLION DOLLARS

	DDT+E	AV. UNIT PROD
AIRFRAME	230.29	72.70
TANK INSULATION	1.59	1.26
TPS	120.00	4.98
FUEL SYSTEM	32.07	7.35
TANKAGE	114.52	23.69
ROCKET ENGINES	654.70	7.43
AIR BREATHING ENG.	0.0	0.0
APU	14.60	1.60
ON ORBIT MANEUV.SYS	111.00	3.78
AVIONICS	520.00	64.00
ELECT. PWR. CRYO.	10.60	1.70
BAT/FUEL CELLS	25.50	2.08
ENV. CONTROL SYS.	60.00	1.80
REACTION CONT. SYS.	222.62	6.51
TOT SUBSYSTEMS	964.72	81.47
TEST OPERATIONS	97.30	
TEST FL PROPELLANTS	0.25	
TEST AIRFRAME	348.98	
TEST TPS	23.50	
TEST FUEL SYSTEM	35.29	
TEST TANKAGE	113.70	
TEST TANK INSUL.	6.04	
TEST ENGINES	35.65	
TEST REPL. HARDWARE	1.78	
TEST 1ST STRAPON	0.0	
TEST 2ND STRAPON	0.0	
TEST SUBSYSTEMS	391.06	
TOT TEST HARDWARE	956.41	
SUB TOTAL	3171.64	198.88
1ST STAGE STRAP-ON	0.0	0.0
1ST STAGE ENGINE		
2ND STAGE STRAP-ON	0.0	0.0
1ST STG.RECOV.DEVC.	0.0	0.0
2 PC.STRAPON SPARES		0.0
10 PC. CORE SPARES		19.89
SUB TOTAL DDT+E	3171.64	
TEST FAC/GSE	44.70	
MFG FAC NON REC.	16.00	
TRANSPORT. NON REC.	0.0	
SUB TOTAL NON REC	3232.34	
10 PC SYS INT + MGT	323.25	

TABLE 4.3-8. COST SUMMARY - MIDTERM (COMPUTER FORMAT) ORBITER (Cont)

TOTAL	REC.	3555.75			
NON					
OPERATIONS					
PROPELLANTS/FLIGHT			0.08		
REPLENISHMENT SPARES/FLT			0.45		
OVERHAUL/FLT			0.14		
TRANSPORTATION/FLT			0.0		
TEST HARDWARE CONV.			29.96		
FAC/GSE REF.MTL./FLT. RATE	100.00		0.30		
FAC/GSE REF.MTL./FLT. RATE	220.00		0.14		
FAC/GSE REF.MTL./FLT. RATE	365.00		0.08		
FAC/GSE REF.MTL./FLT. RATE	445.00		0.07		
GS MANPOWER/YR AT RATE OF	100.		0.0		
GS MANPOWER/YR AT RATE OF	220.		0.0		
GS MANPOWER/YR AT RATE OF	365.		0.0		
GS MANPOWER/YR AT RATE OF	445.		0.0		
GSE+FACILITIES FOR RATE OF	100.		0.0		
GSE+FACILITIES FOR RATE OF	220.		0.0		
GSE+FACILITIES FOR RATE OF	365.		0.0		
GSE+FACILITIES FOR RATE OF	445.		0.0		
ADDIT.PROD FAC FOR RATE OF	100.00		0.0		
ADDIT.PROD FAC FOR RATE OF	220.00		0.0		
ADDIT.PROD FAC FOR RATE OF	365.00		0.0		
ADDIT.PROD FAC FOR RATE OF	445.00		0.0		
				SPC	TOTAL
COST PER FLIGHT AT RATE OF	100.00		0.98	0.05	1.03
COST PER FLIGHT AT RATE OF	220.00		0.81	0.04	0.86
COST PER FLIGHT AT RATE OF	365.00		0.76	0.04	0.80
COST PER FLIGHT AT RATE OF	445.00		0.75	0.04	0.78

Table 4.3-9. Cost Spread - Midterm (Computer Format) - Orbiter

CONFIGURATION FLIGHTS= 445.0
C4 ORBITER

R+D	STG1 REC DEV	STG 2, PROD	STG 1 REC DEV	STG 2
0.0	0.0	0.0	0.0	0.0

PROD LRN CURVE, STRAIGHT UNIT
STG 1= 0.950 REC DEV= 0.900 STG 2= 0.900

DDTE COSTS

YEAR	ORBITER	STAGE 1	STAGE 2	TEST OPS	GSE+FAC	TOTAL + 10 PC
1972.	0.5045E 02	0.0	0.0	0.1597E 01	0.9961E 00	0.5835E 02
1973.	0.2774E 03	0.0	0.0	0.8778E 01	0.5476E 01	0.3208E 03
1974.	0.5504E 03	0.0	0.0	0.1742E 02	0.1087E 02	0.6365E 03
1975.	0.7281E 03	0.0	0.0	0.2304E 02	0.1437E 02	0.8421E 03
1976.	0.7307E 03	0.0	0.0	0.2312E 02	0.1443E 02	0.8450E 03
1977.	0.5296E 03	0.0	0.0	0.1708E 02	0.1065E 02	0.6241E 03
1978.	0.1680E 03	0.0	0.0	0.6265E 01	0.3908E 01	0.2290E 03
1979.	0.0	0.0	0.0	0.0	0.0	0.0
1980.	0.0	0.0	0.0	0.0	0.0	0.0
1981.	0.0	0.0	0.0	0.0	0.0	0.0
1982.	0.0	0.0	0.0	0.0	0.0	0.0
1983.	0.0	0.0	0.0	0.0	0.0	0.0
1984.	0.0	0.0	0.0	0.0	0.0	0.0
1985.	0.0	0.0	0.0	0.0	0.0	0.0
1986.	0.0	0.0	0.0	0.0	0.0	0.0
1987.	0.0	0.0	0.0	0.0	0.0	0.0
TOTALS	0.3075E 04	0.0	0.0	0.9730E 02	0.6070E 02	0.3556E 04

PRODUCTION COSTS

YEAR	ORBITER	STAGE 1	STAGE 2	TOTAL + 5 PC
1972.	0.0	0.0	0.0	0.0
1973.	0.0	0.0	0.0	0.0
1974.	0.0	0.0	0.0	0.0
1975.	0.0	0.0	0.0	0.0
1976.	0.0	0.0	0.0	0.0
1977.	0.2596E 02	0.0	0.0	0.3146E 02
1978.	0.1094E 03	0.0	0.0	0.1149E 03
1979.	0.1094E 03	0.0	0.0	0.1149E 03
1980.	0.1094E 03	0.0	0.0	0.1149E 03
1981.	0.1094E 03	0.0	0.0	0.1149E 03
1982.	0.0	0.0	0.0	0.0
1983.	0.0	0.0	0.0	0.0
1984.	0.0	0.0	0.0	0.0
1985.	0.0	0.0	0.0	0.0
1986.	0.0	0.0	0.0	0.0
1987.	0.0	0.0	0.0	0.0
TOTALS	0.4675E 03	0.0	0.0	0.4909E 03

OPERATING COSTS

YEAR	FAC/GSE/MPR	CRB REFRB	STG1 REFRB	PRPLNTS	TOTAL+5PC	GRND TOTL
1972.	0.0	0.0	0.0	0.0	0.0	0.5835E 02
1973.	0.0	0.0	0.0	0.0	0.0	0.3208E 03
1974.	0.0	0.0	0.0	0.0	0.0	0.6365E 03
1975.	0.0	0.0	0.0	0.0	0.0	0.8421E 03
1976.	0.0	0.0	0.0	0.0	0.0	0.8450E 03
1977.	0.0	0.0	0.0	0.0	0.0	0.6555E 03
1978.	0.3035E 01	0.5943E 01	0.0	0.8271E 00	0.1030E 02	0.3541E 03
1979.	0.3035E 01	0.8915E 01	0.0	0.1241E 01	0.1385E 02	0.1287E 03
1980.	0.3035E 01	0.1189E 02	0.0	0.1654E 01	0.1740E 02	0.1323E 03
1981.	0.3035E 01	0.1783E 02	0.0	0.2481E 01	0.2451E 02	0.1394E 03
1982.	0.3035E 01	0.2377E 02	0.0	0.3308E 01	0.3162E 02	0.3162E 02
1983.	0.3035E 01	0.2972E 02	0.0	0.4135E 01	0.3873E 02	0.3873E 02
1984.	0.3035E 01	0.3566E 02	0.0	0.4962E 01	0.4584E 02	0.4584E 02
1985.	0.3035E 01	0.4160E 02	0.0	0.5789E 01	0.5295E 02	0.5295E 02
1986.	0.3035E 01	0.4457E 02	0.0	0.6203E 01	0.5650E 02	0.5650E 02
1987.	0.3035E 01	0.4457E 02	0.0	0.6203E 01	0.5650E 02	0.5650E 02
TOTALS	0.3035E 02	0.2645E 03	0.0	0.3680E 02	0.3482E 03	0.4395E 04

TABLE 4.3-10. DISCOUNTED COST SPREAD - MIDTERM (COMPUTER FORMAT) - ORBITER

INTEREST RATES & TOTAL PRESENT VALUES

BASE YEAR= 1970.

2.00	0.3795E 04	4.00	0.3297E 04	6.00	0.2879E 04	8.00	0.2526E 04
10.00	0.2227E 04	12.00	0.1971E 04	14.00	0.1751E 04	16.00	0.1562E 04
18.00	0.1397E 04	20.00	0.1254E 04				

DISCOUNTED CASH FLOW AT 10.000 -

YEAR	ANN. COST	CUM.	DISCOUNT	CUM.
1972.	0.5835E 02	0.5835E 02	0.4384E 02	0.4384E 02
1973.	0.3208E 03	0.3791E 03	0.2191E 03	0.2629E 03
1974.	0.6365E 03	0.1016E 04	0.3952E 03	0.6582E 03
1975.	0.8421E 03	0.1858E 04	0.4753E 03	0.1133E 04
1976.	0.8450E 03	0.2703E 04	0.4336E 03	0.1567E 04
1977.	0.6555E 03	0.3358E 04	0.3058E 03	0.1873E 04
1978.	0.3541E 03	0.3712E 04	0.1502E 03	0.2023E 04
1979.	0.1287E 03	0.3841E 04	0.4962E 02	0.2073E 04
1980.	0.1323E 03	0.3973E 04	0.4636E 02	0.2119E 04
1981.	0.1394E 03	0.4113E 04	0.4441E 02	0.2164E 04
1982.	0.3162E 02	0.4144E 04	0.9160E 01	0.2173E 04
1983.	0.3873E 02	0.4183E 04	0.1020E 02	0.2183E 04
1984.	0.4584E 02	0.4229E 04	0.1097E 02	0.2194E 04
1985.	0.5295E 02	0.4282E 04	0.1152E 02	0.2205E 04
1986.	0.5650E 02	0.4338E 04	0.1118E 02	0.2217E 04
1987.	0.5650E 02	0.4395E 04	0.1016E 02	0.2227E 04

TOTAL= 0.2227E 04

INTEREST RATES & TOTAL PRESENT VALUES

BASE YEAR= 1970.

2.00	0.3795E 04	4.00	0.3297E 04	6.00	0.2879E 04	8.00	0.2526E 04
10.00	0.2227E 04	12.00	0.1971E 04	14.00	0.1751E 04	16.00	0.1562E 04
18.00	0.1397E 04	20.00	0.1254E 04				

DISCOUNTED CASH FLOW AT 5.000 -

YEAR	ANN. COST	CUM.	DISCOUNT	CUM.
1972.	0.5835E 02	0.5835E 02	0.5040E 02	0.5040E 02
1973.	0.3208E 03	0.3791E 03	0.2639E 03	0.3143E 03
1974.	0.6365E 03	0.1016E 04	0.4987E 03	0.8130E 03
1975.	0.8421E 03	0.1858E 04	0.6284E 03	0.1441E 04
1976.	0.8450E 03	0.2703E 04	0.6006E 03	0.2042E 04
1977.	0.6555E 03	0.3358E 04	0.4437E 03	0.2486E 04
1978.	0.3541E 03	0.3712E 04	0.2283E 03	0.2714E 04
1979.	0.1287E 03	0.3841E 04	0.7901E 02	0.2793E 04
1980.	0.1323E 03	0.3973E 04	0.7733E 02	0.2870E 04
1981.	0.1394E 03	0.4113E 04	0.7761E 02	0.2948E 04
1982.	0.3162E 02	0.4144E 04	0.1677E 02	0.2965E 04
1983.	0.3873E 02	0.4183E 04	0.1956E 02	0.2984E 04
1984.	0.4584E 02	0.4229E 04	0.2205E 02	0.3006E 04
1985.	0.5295E 02	0.4282E 04	0.2426E 02	0.3031E 04
1986.	0.5650E 02	0.4338E 04	0.2465E 02	0.3055E 04
1987.	0.5650E 02	0.4395E 04	0.2348E 02	0.3079E 04

= 0.3079E 04

TABLE 4.3-11. COST SUMMARY - MIDTERM - 445 FLIGHTS

	BOOSTER	ORBITER	TOTAL
• DDT&E - TOTAL ($M)	3344.57	3555.80	6900.37
CORE VEHICLE	1402.78	2117.89	3520.67
STAGE 1 (SRM)	0	0	0
STAGE 2 (DROP TANKS)	0	0	0
TEST VEHICLES	1161.07	956.41	2117.48
TEST OPS	172.14	97.55	269.69
TEST FACILITY/GSE	278.90	44.70	323.60
MFG FACILITY	25.63	16.00	41.63
SYS. INT./MGMT.	304.05	323.25	627.30
• PRODUCTION - TOTAL	1121.36	490.87	1612.23
CORE VEHICLE	1030.62	437.54	1468.16
STAGE 1 (SRM)	0	0	0
STAGE 2 (DROP TANKS)	0	0	0
TEST VEH. CONVERSION	37.34	29.96	67.30
PROD. FAC (ADD'L)	0	0	0
SYS INT/MGMT.	53.4	23.37	76.77
• OPERATIONS - TOTAL	1126.86	348.23	1475.09
OPS AND SUPPORT	349.10	0	349.10
MATERIALS	525.80	301.3	827.10
OPS FAC/GSE (ADD'L)	198.30	30.35	228.65
SYS INT/MGMT.	53.66	16.58	70.24
• TOTAL PROGRAM			9988

TABLE 4.3-12. COST SUMMARY BY FLIGHT RATE - BOOSTER AND ORBITER

		FLIGHT RATE			
		100	220	365	445
BOOSTER	DDT&E	3345	3345	3345	3345
	PRODUCTION	399.9	399.9	760.6	1121
	OPERATIONS	484.4	714.2	982.2	1127
	TOTAL	4229	4459	5087	5593
	PEAK ANNUAL FUNDING	794.8	794.8	794.8	794.8
ORBITER	DDT&E	3556	3556	3556	3556
	PRODUCTION	31.46	31.46	261.2	490.9
	OPERATIONS	103	188.3	291.3	348.2
	TOTAL	3690	3776	4108	4395
	PEAK ANNUAL FUNDING	845	845	845	845

TABLE 4.3-13. COST SUMMARY BY FLIGHT RATE - BOOSTER AND ORBITER (C-4)

PROGRAM		FLIGHT RATE			
		100	220	365	445
	DDT&E	6901	6901	6901	6901
	PRODUCTION	431.36	431.36	1021.8	1611.9
	OPERATIONS	587.4	902.5	1273.5	1475.2
	TOTAL	7919	8235	9195	9988
	PEAK ANNUAL FUNDING	1639.8	1639.8	1639.8	1639.8

TABLE 4.3-14. NASA SUBSYSTEM COST COMPARISON

	DC-3 Subsystems		Phase B Subsystems*		
	DDT&E w/o Test Unit	Unit Cost	DDT&E w/3 Test Units	DDT&E w/o 3 Test Units	Unit Cost
Orbiter					
Avionics	520	64	500	425	25
Power	339	5.4	120	90	10
ECLSS	60.	1.8	100	70	10
Booster					
Avionics	339	61	600	540	20
Power	21	3.6	130	100	10
ECLSS	14	0.7	40	25	5

*NASA/MSC LTR-EA9-A9-70-1110-2

C-4 (445 Flights)		
DDT&E	6901	6909
Production	1612	1416
Operations	1475	1475
Total Program	9988	9800

4.3.2 Concept C Configuration Cost Comparison

4.3.2.1 6-Week Comparison (C-1 - C-4)

Included in this section is a summary of the initial study matrix for Concept C and the results of the first six week review and evaluation (Tables 4.3-15 through 4.3-17 and figures 4.3-1 and 4.3-2).

Basic concepts considered included SRM strap-ons (C-1), J2S engines, and gas generator vs topping cycle configurations. The cost significance of each of these factors was evaluated by Grumman engineering and cost personnel. The concept comparison was made between optimized point designs and covered all aspects of development, procurement and operational costs.

The results of this study effort precipitated a continuation of the C-4 and C-2 designs.

The following charts contain data on the costed point designs and the resulting program costs and annual funding profiles.

TABLE 4.3-15. CONFIGURATION C POINT DESIGN SUMMARY - 6 WEEKS

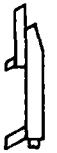
	C-1	C-2 Baseline		C-3	C-4
		C-2 Inital	C-2 Final		
Launch Configs					
Orbiter	J2S	J2S Retrofit To →	H. P.	Optimized H. P. Eng With Topping Cycle	Optimized H. P. With Gas Generator (High Chamber Press, Low Pump Discharge Press.)
Engines					
Booster	J2S+ 120" Expend. Strap-On SRM's	J2S+ 120" Expend. Strap-On SRM's Retrofit To →	H.P. Eng Strap on SRM's Deleted	Optimized H. P. Eng With Topping Cycle	Optimized H. P. With Gas Generator (High Chamber Press, Low Pump Discharge Press.)

TABLE 4.3-16. "C" SUMMARY EVALUATION - 6 WEEKS

		C-1	C-2I	C-2F	C-3	C-4
SCREENING	UNITS	16/3 J2S 2-120"SRM	16/3 J2S 2-120"SRM	16/3HP (TC)	11/2 HP (TC)	11/2 HP (GG)
PEAK ANNUAL FUNDING	B $	1.78	1.84		1.94	1.94
TOTAL PROGRAM COST	B $	10.835	10.688		10.278	10.278
PAYLOAD SENSITIVITY	LB/%W_{IB}	849	750		733	720
	LB/%W_{IO}	1876	1871		1849	1845
	LB/SEC_B	804	658		648	653
	LB/SEC_O	758	723		720	735

TABLE 4.3-17. "C" CONFIGURATION COMPARISON (COSTED DESIGN POINT)

		C-1	C-2I	C-2F	C-3	C-4
• ENGINES Boost/Orb - Type		16/3-J2S	16/3-J2S	16/3-Top. Cyc.	11/2-Top Cyc.	11/2-Gas Gen.
SRM		2-120"SRM	2-120"SRM			
• OLOW	(LBS)	711,810	716,230	714,490	711,500	726,030
• BLOW	(LBS)	2,591,540	2,623,270	2,623,110	2,568,000	2,613,670
• GLOW	(LBS)	4,482,000	4,856,000	3,337,600	3,279,500	3,339,700
• ORBITER T/W		1.14	1.14	1.32	1.25	1.25
• LIFT OFF T/W		1.45	1.44	1.25	1.25	1.25
• ORBITER ΔV	(FT/SEC)	15,820	15,820	16,400	16,460	16,600
• W PROPELLANT	(LBS)					
ORBITER		473,673	476,722	476,722	476,185	491,161
BOOSTER		2,089,358	2,112,629	2,112,629	2,069,248	2,116,830
STRAP-ONS		1,297,000	1,297,000	--	--	--
• AIR BREATHERS		(7) JTF-22	(7) JTF-22	(7) JTF-22	(7) JTF-22	(7) JTF-22

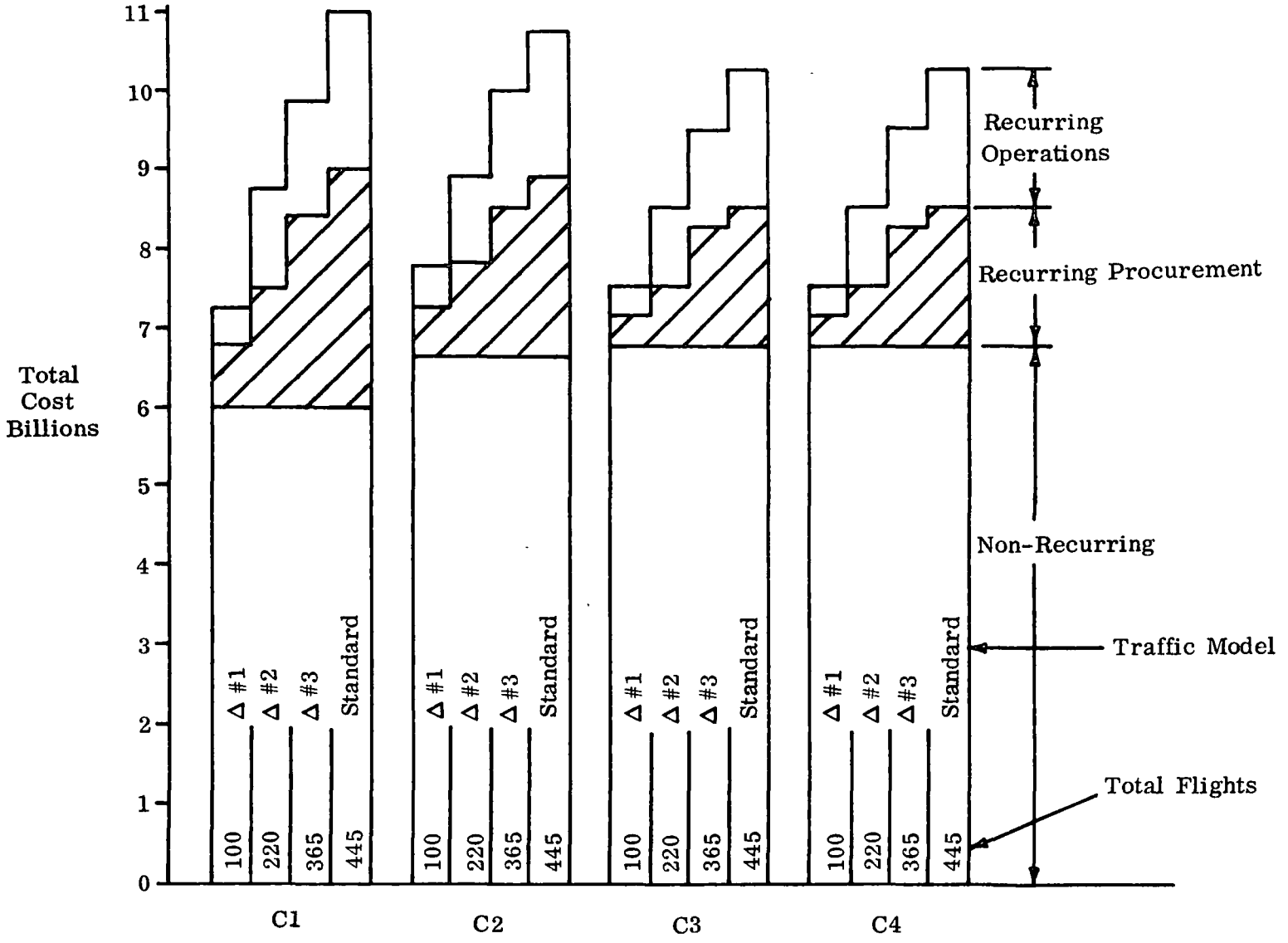


Figure 4.3-1. 'C' - 10 Year Total Program Cost Comparison - 6 Weeks

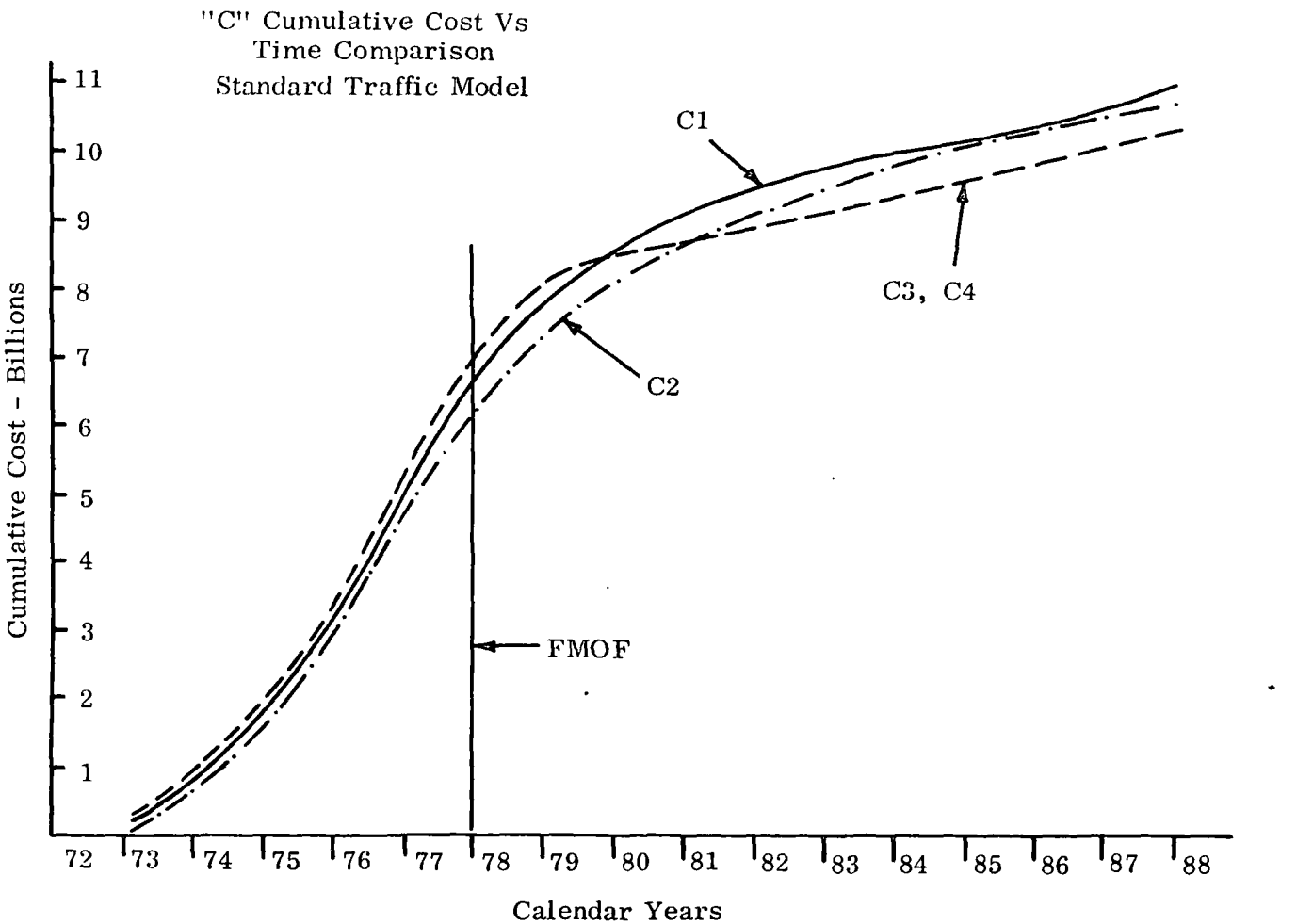


Figure 4.3-2. "C" Cumulative Cost vs Time Comparison Standard Traffic Model - 6 Weeks

4.3.2.2 6-Week - 3-Month Cost Refinements

The initial study matrix was evaluated using the GAC Space Shuttle Cost Model. As design data continued to be expanded in technical areas, the CER's used to formulate the cost components were re-evaluated and in some cases refined through consultation with personnnel from Grumman engineering, manufacturing, test and operations. Vendor data was incorporated as it became available. Significant differences present in the 3 month evaluation were:

a) More precise definition of the number and configuration of the test vehicles.

b) Production quantities.

Flight	6 Week		12 Week	
	0	B	0	B
100	1	1	0	0
220	2	2	0	0
365	3	3	1	1
445	4	4	2	2

c) The TPS material cost was altered to reflect latest manufacturing data.

d) Tanks and fuel system were extracted from basic A.M.P.R. and costed separately.

e) Provision was made for systems integration and management categories.

A comparison of 6 week vs 12 week results is included in Table 4.3-18. The overall effect of these cost refinements is lower program cost due primarily to the fewer number of test and production vehicles.

TABLE 4.3-18. 6 WEEK - 3-MONTH DATA COMPARISON, 445 FLIGHTS

	C4	
	6 Weeks	12 Weeks
RDT&E Costs	6,704	6,530
Total Program Costs	10,278	9,799
Peak Annual Funding Prior to FMDF	1,940	1,560
GLOW, 10^6 Lbs	3,340	3,660

4.3.2.3 3 Month Results - C-4

Presented in this section are the C-4 point design characteristics, detailed costs and a summary of study results which also includes data on the C-4R and Minimum Core Vehicles. The cost data reflect a combination of CER's and point estimates based on detailed evaluation and experience.

Table 4.3-19 contains vehicle technical characteristics and tables 4.3-20 and 4.3-21 contain cost results. C-4R results are presented on Tables 4.3-22 and 4.3-23 and Figure 4.3-3. Minimum Core Vehicle results are presented in Figures 4.3-4 and 4.3-5.

TABLE 4.3-19. C-4 VEHICLE CHARACTERISTICS - 3 MONTHS

	Orbiter	Booster
• Inert Weight, Lb	197,358	527,541
Cargo, Lb	25,000	-----
On-Orbit Propellant, Lb	25,817	-----
• Injection Weight, Lb	248,175	527,541
Injection Propellant, Lb	485,825	2,402,459
• LOW, Lb	734,000	2,930,000
• GLOW, Lb	3,664,000	
• Δ V, fps	15,950	15,123
• Propellant Fraction	.716	.820

	Orbiter		Booster	
	S.L.	Vac.	S.L.	Vac.
• Thrust/Engine		458,000	382,000	441,000
• Isp, Sec		456.8	382	440.5
• No. of Engines	2		12	

TABLE 4.3-20. C-4 DETAILED COSTS, 445 FLIGHTS - 3 MONTHS

● DDT&E - Total ($ B)	6.53	
- Orbiter		2.10
- Booster		1.03
- Test Vehicles		2.20
- Test Ops & Support		0.27
- Test Fac/GSE		0.32
- Mfg Fac		0.04
- Sys Int/Mgt		0.57
● Production - Total ($ B)	1.28	
- Orbiter		0.44
- Booster		0.68
- Test Vehicles		0.10
- Prod Fac (Add'l)		-
- Sys Int/Mgt		0.06
● Operations - Total ($ B)	1.98	
- Ops & Support		0.36
- Materials		1.49
- Ops Fac/GSE (Add'l)		0.03
- Sys Int/Mgt		0.10
● Total Program ($ B)	9.79	

TABLE 4.3-21. C-4 SUMMARY OF STUDY RESULTS - 3 MONTHS

	220 Flights	445 Flights
• Cost		
- DDT&E, $ B	6.53	6.53
- Peak Annual, $ B	1.56	1.56
- Total Program, $ B	7.66	9.79
- Per Flight,		
Ops + Expend/Flt, $ M	4.65	4.39
Ops + Prod/Flt, $ M	5.10	7.30
• Configuration		
- GLOW, Lb	3,664,000	
- BLOW, Lb	2,930,000	
- OLOW, Lb	734,000	
• Payload Sensitivity		
- ΔPL/% Boost. Dry Wt, Lb	812	
- ΔPL/% Orb Dry Wt, Lb	1856	
- ΔPL/Sec Boost. I_{SP}, Lb	768	
- ΔPL/Sec Orb I_{SP}, Lb	754	
• Cost Sensitivity		
- $M/% Total inert wt.	110	
- $M/% I_{SP} (Stack)	491	

TABLE 4.3-22. C REUSABLE BOOSTER, ORBITER, 445 FLIGHTS - 3 MONTHS

	C-4	C-4R
	Reusable Booster, Orbiter HiPc GG Engines	Booster: J-2S + SRM'S HiPc GG Orbiter: J-2S HiPc GG
● DDT&E, $B	6.53	6.83
● Total Program, $B	9.79	10.91
● Cost/Flight $M – (No Amortized Prod)	3.13	
● Peak Annual Funding $B	1.56	1.62
● Payload Sensitivy (Lb%W_i)	2668	2911
● Cost Sensitivity ($M/% W_i)	110	

TABLE 4.3-23. C-4R WEIGHT COMPARISON, J-2S RETROFIT - 3 MONTHS

			C-4R(F)		C-4R(I)		
	Orbiter	Booster	Orbiter	Booster	Orbiter	Booster	SRM*
Inert Wt (Lb)	203,950	536,000	203,950	556,200	210,459	555,160	294,700
Payload (Lb)	25,000		25,000		25,000		
On-Orbit Prop (Lb)	26,550		26,550		27,408		
Injection Prop (Lb)	493,500	2,460,000	493,500	2,498,640	493,500	2,520,770	1,990,000
Lift-Off Wt (Lb)	749,000	2,996,000	749,000	3,054,840	756,367	3,075,930	2,284,800
GLOW	3,745,000		3,803,840		6,117,097		
Engine I_{sp} (Sec) SL		382		382		365.8	233
Engine I_{sp} (Sec) Vac	456.8	440.5	456.8	440.5	444	419	271
Eng Thrust (Lb) SL		390,000		390,000		253,200**	2,280,000
Eng Thrust (Lb) Vac	466,000	450,000	466,000	450,000	282,000	290,000	2,650,000

* Total Weight Shown for Two 156-In. SRM
** Add'l J-2S Dev. Req'd

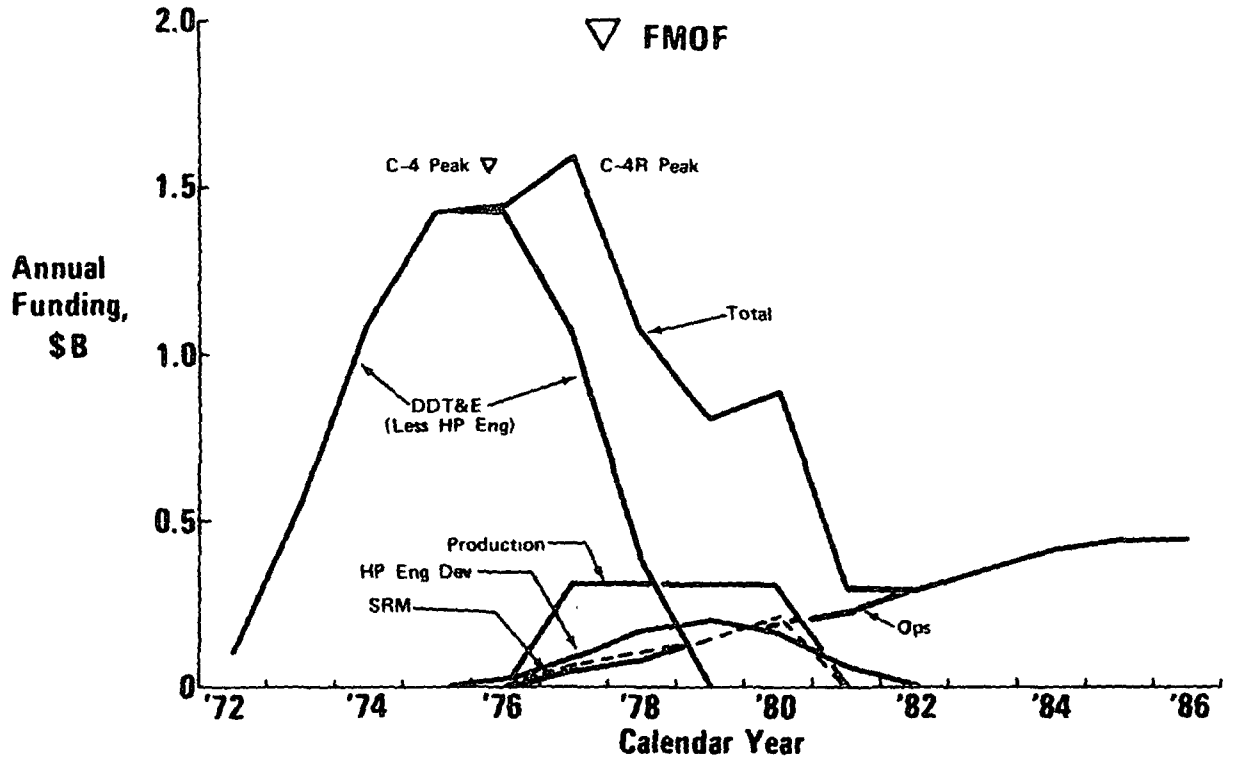


Figure 4.3-3. C-4R Annual Funding Requirements, 445 Flights - 3 Months

- Core Vehicle Sized to Deliver: 25K; 15K; 5K; -5K, -15K Lb
- Payload with SRM's: 25K, Lb
- Core Vehicle Uses GG Engines
- 120 In. SRM Inert Weight Characteristics Used for Propellant Weights < 720,000 Lb
- 156 In. SRM Inert Weight Characteristics Used for Propellant Weights > 720,000 Lb
- C-4 Orbiter/Booster Inert Weight Characteristics
  - 15 X 60 Cargo Bay
  - 10% Contingency
  - Forward Docking
  - Booster Lands at Launch Site
  - No Orbiter Airbreathers
- Max q Constrained to Be Less Than 500 psf

Figure 4.3-4. C Minimum Core Vehicle Study Ground Rules

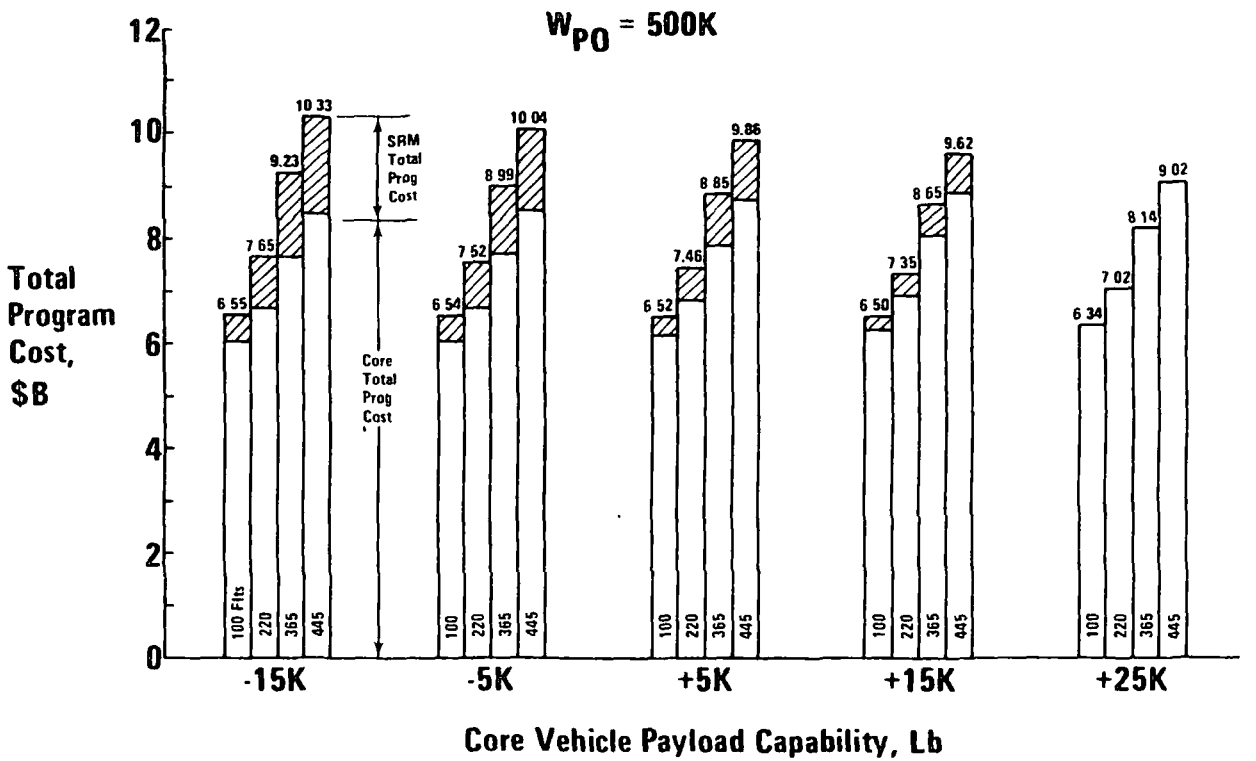


Figure 4.3-5. Minimum Core Vehicle, Cost Trending - 3 Months

4.3.2.4 3-Month to Midterm Cost Refinements

The changes made to the cost model after the 3-month review include the following:

DDT&E

- Elimination of Orbiter/Booster DDT&E commonality
- Revision of cryogenic tank development factor

Production

- Addition of (1) booster in all flight rates

Operation

- Improvement of TPS refurbishment computation
- Addition of GSE/facilities annual refurbishment materials cost

4.3.3 NASA Cost Form

This section includes completed NASA cost estimate forms "A" and "D" (ref. MF003M) for Configuration C-4.

The forms display total cost and fiscal year distribution for C-4.

DDT&E	Figure 4.3-6 and -7
Production	Figure 4.3-8 and -9
Operations	Figure 4.3-10 and -11

COST ESTIMATE DATA FORM A

X NON-RECURRING (DDT&E)

_____ RECURRING (PRODUCTION)

_____ RECURRING (OPERATIONS)

DATE _____

PAGE ___ of ___

VEHICLE CONFIGURATION C-4

NO. OF FLTS. 445

WBS IDENTIFICATION NO.	WBS ITEM NAME	WBS ITEM COST	NUMBER OF UNITS
	Orbiter	2585.6	3
	Booster	2724.4	2
	Main Engine	654.7	-
	Flight Test	308.5	-
	Program Management	627.3	-

Figure 4.3-6. Cost Estimate Data Form A - C4 (DDT&E)

COST ESTIMATE DATA FORM D

X NON-RECURRING (DDT&E) DATE _____

_____ RECURRING (PRODUCTION) PAGE ____ of ___

_____ RECURRING (OPERATIONS)

VEHICLE CONFIGURATION C-4 NO. of FLTS. 445

PROJECT	FY										
WBS ITEMS	72	73	74	75	76	77	78	79	80	81	82
ORBITER	8.5	171	457.3	656.0	656	457.3	171.0	8.0			
BOOSTER	6.1	130.2	371	582.6	668	583	339	44.5			
MAIN ENGINE	2.1	43.4	116	166	166	116	43.2	2			
FLIGHT TEST	.34	9.1	29	53	73	78	57	9.06			
PROGRAM MANAGEMENT	44.8	89.6	89.6	89.6	89.6	89.6	89.6	45.3			

Figure 4.3-7. Cost Estimate Data Form D - C-4 (DDT&E)

COST ESTIMATE DATA FORM A

_____ NON-RECURRING (DDT&E) DATE _____

__X__ RECURRING (PRODUCTION) PAGE ____ of ____

_____ RECURRING (OPERATIONS)

VEHICLE CONFIGURATION C-4 NO. OF FLTS. 445

WBS IDENTIFICATION	WBS ITEM NAME	WBS ITEM COST	NUMBER OF UNITS
	ORBITER	451.2	2
	BOOSTER	926.8	3
	MAIN ENGINE	157.5	40
	FLIGHT TEST	*	-
	PROGRAM MANAGEMENT	76.7	-

*INCLUDED IN BOOSTER AND ORBITER COSTS

Figure 4.3-8. Cost Estimate Data Form A - C-4 (PRODUCTION)

COST ESTIMATE DATA FORM D

_____ NON-RECURRING (DDT&E) DATE _____

_X_ RECURRING (PRODUCTION) PAGE ___ of ___

_____ RECURRING (OPERATIONS)

VEHICLE CONFIGURATION C-4 NO. OF FLTS. 445

PROJECT	FY							
WBS ITEMS	77	78	79	80	81	82	83	84
ORBITER	14.9	67.7	105.3	105.3	105.3	52.7		
BOOSTER	18.5	92.6	148.3	148.3	148.3	148.3	148.3	74.2
MAIN ENGINE	-	13.8	27.6	27.6	27.6	25.5	23.5	11.9
FLIGHT TEST*	-	-	-	-	-	-	-	-
PROGRAM MANAGEMENT	3.3	10.4	10.8	10.8	12.8	12.8	10.4	5.4

*INCLUDED IN ORBITER AND BOOSTER COSTS

Figure 4.3-9. Cost Estimate Data Form D - C-4 (PRODUCTION)

COST ESTIMATE DATA FORM A

_____ NON-RECURRING (DDT&E) DATE _____

_____ RECURRING (PRODUCTION) PAGE ___ of ___

__X__ RECURRING (OPERATIONS)

VEHICLE CONFIGURATION C-4 NO. of FLTS. 445

WBS IDENTIFICATION NO.	WBS ITEM NAME	WBS ITEM COST	NUMBER OF UNITS
	OPERATIONS	1404.8	
	PROGRAM MANAGEMENT	70.2	

Figure 4.3-10. Cost Estimate Data Form A - C-4 (OPERATIONS)

COST ESTIMATE DATA FORM D

_____ NON-RECURRING (DDT&E)

_____ RECURRING (PRODUCTION)

_X_ RECURRING (OPERATIONS)

DATE _____

PAGE _____ of _____

VEHICLE CONFIGURATION C-4

No. OF FLTS. 445

PROJECT	FY												
WBS ITEMS	77	78	79	80	81	82	83	84	85	86	87	88	89
OPERATIONS	118.7	141.3	54.4	64.1	78.8	98.5	117.9	137.2	156.8	171.5	176.3	89.7	
PROGRAM MANAGEMENT	1.5	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	1.85	

Figure 4.3-11. Cost Estimate Data Form D - C-4 (OPERATIONS)

Section 5

CONCEPT COST COMPARISON

Five configurations were selected for the A, B and C program cost comparison. The alternate Space Shuttle programs include: Stage and-one-half/Thrust Augmented (1 1/2 TA), Expendable Liquid Rocket Booster/Reusable Orbiter (Liq B/RO). Expendable Solid Rocket Booster/Reusable Orbiter (Sol B/RO), Fully Reusable Orbiter/Booster (Reus O/B), and Minimum Risk Fully Reusable (Min Risk/FR). The Min Risk/FR is a programmatic option combining an interim S1C/Reusable Orbiter with delayed development of a Reusable Booster. Further discussion on programmatic alternatives is contained in Section 6.

The principal topics within this section are as follows:

- Configuration Descriptions
- Program Cost Comparison

Section 5.1 contains a general description of the selected configurations noting those features which contribute differences in non-recurring and recurring program costs.

Section 5.2 contains a comparative breakdown of total program costs for DDT&E, Production and Operations, plus detailed DDT&E costs and first unit costs. The effect of different traffic models on total program costs are also included together with comparative launch costs per flight, cost objectives related to the Phase B cost bogies, and program cost sensitivities to discounting.

5.1 Configuration Descriptions

The configuration selected for the mid term program cost comparison include 1-1/2 TA (A-3A), Liq B/RO (B-2D), Sol B/RO (B-2I), Reus O/B (C-4), and Min Risk/FR ($C\text{-}4_{I/II}$). Typical launch arrangements for each configuration are shown in Figure 5.1-1. It should be noted that only the interim expendable S1C launch arrangement is illustrated for the Min Risk/FR Program. Once the Min Risk/FR reusable booster becomes available, the launch arrangements will be identical to that noted for the Reus O/B Program.

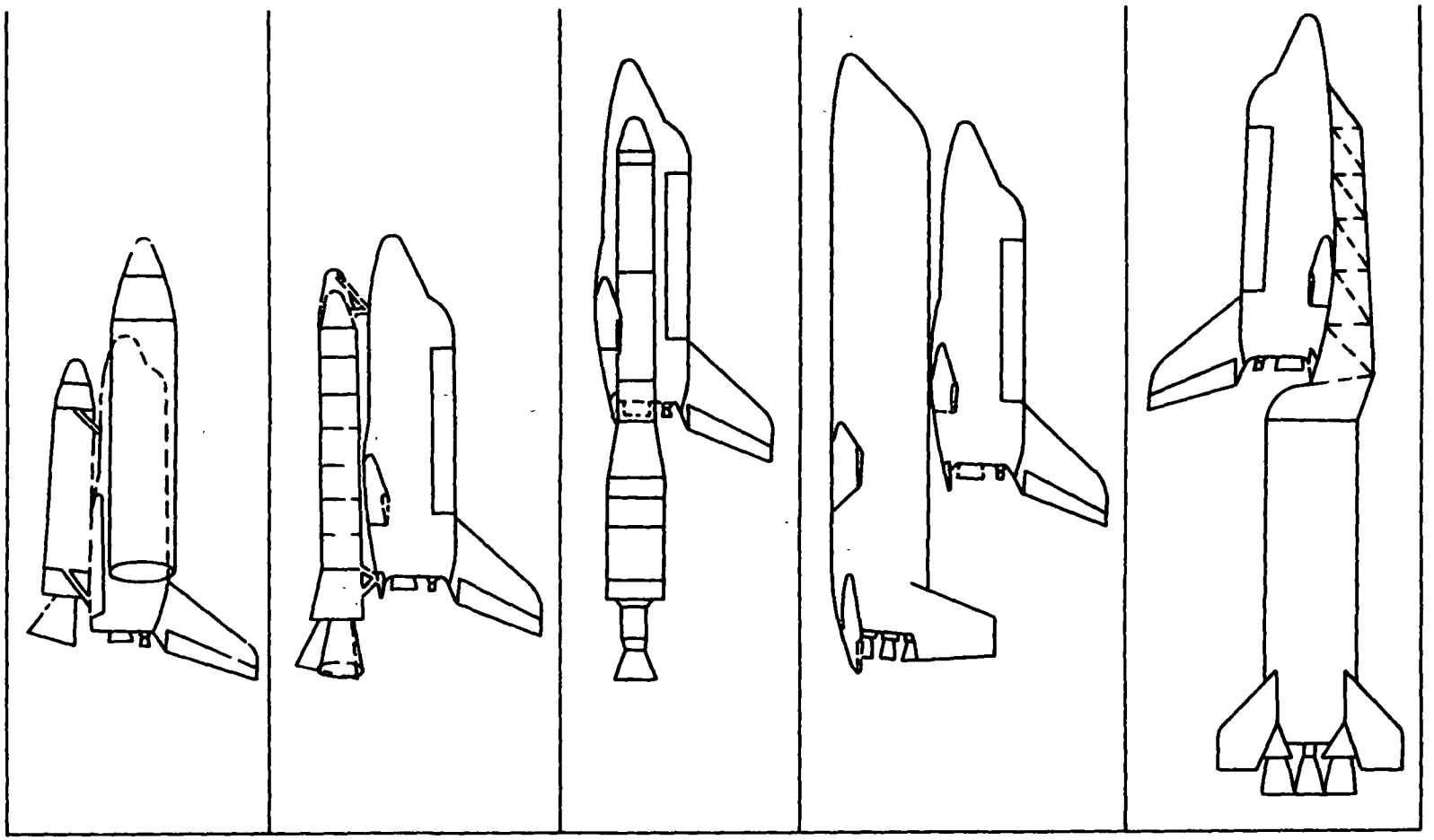


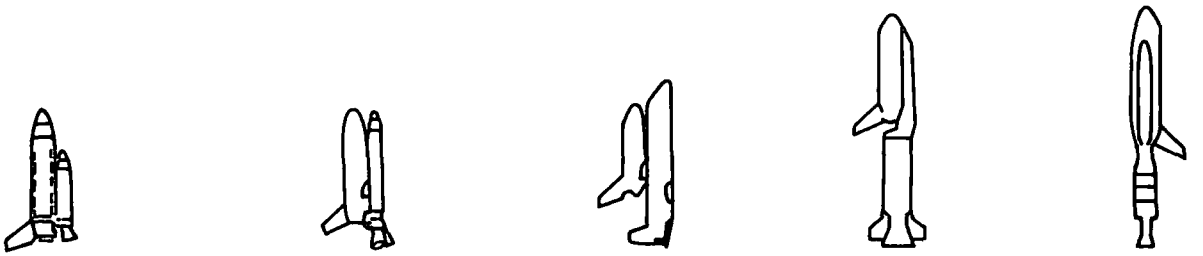
Figure 5.1-1. Concept Launch Arrangements

All programs have been designed with a reusable cryogenic fueled orbiter. Except for 1-1/2/TA, the orbiter propulsion is designed to operate subsequent to booster staging for the final thrust into orbit. However, in 1-1/2/TA, the orbiter propulsion operates from liftoff through strap-on booster staging and final thrusting for orbit insertion. Hence, the mode of booster operation prior to final staging, its reusability after staging and its propellant characteristics largely determine the size and weight of the launch configuration and its operational costs.

The key features in each program are shown in Figure 5.1-2 and summarized below:

- 1-1/2TA - thrust augmented stage and a half design using parallel operation of a first stage expendable solid rocket motor (SRM) and a second stage pair of expendable cryo cross feed tanks with the reusable winged orbiter
- Liq B/RO - 5 pressure fed storable propellant modules are combined as two stage expendable booster operating in series with a reusable winged cryo fueled orbiter
- Sol B/RO - 3 SRM s are combined as a two stage expendable booster operating in series with a reusable winged cryo fueled orbiter
- Reus O/B - two stage fully reusable shuttle with a winged cryo fueled Booster and Orbiter
- Min Risk/FR - two stage Shuttle with a common reusable Orbiter operating on an interim S1C expendable Booster before phasing into fully reusable Booster operations

The two stage rocket Booster designs, included in the Liq B/RO and Sol B/RO Programs, represent alternate solutions to a new expendable Booster. Either design approach, i.e., large pressure fed storable propulsion or solid propulsion, can be developed into a reliable operational system. However, at this point in time, they do not share equivalent levels of technical maturity. To date, SRM's have undergone



	1 1/2/TA	Sol B/RO	Reus O/B	Int S-IC/RO	Liq B/RO
• Orbiter					
– Propulsion	4-400 K (S.L.) HiPc (TC) Cryo Eng	2-475 K (Vac) HiPc (GG) Cryo Eng	2-458 K - HiPc (GG) Cryo Eng	2-458 K - HiPc (GG) Cryo Eng	2-475 HiPc (GG) Cryo Eng
– Inert Weight, K Lb	170	203	197	197	203
• Booster					
– 1st Stage					
- Propulsion	1-180" SRM 2.625 M Lb	2-180" SRM 4.05 M Lb	12-382K - HiPc (GG) Cryo Eng	S-IC	3-2.6 M PF Store Eng
- Inert Weight, K Lb	159	519	523	498	517
– 2nd Stage					
- Propulsion	2-X Feed Cryo Tanks	1-180" SRM 4.94 M Lb	-	-	2-1.56M PF Store Eng
- Inert Weight, K Lb	108	269	-	-	254
• GLOW M LB	3.38	6.48	3.66	5.01	6.29

Figure 5.1-2. Concept Comparison, Key Features

extensive development effort and have attained operational use in the Titan and Minuteman Programs. Pressure fed storable propulsion systems, however, have not progressed beyond the experimental stage. Hence, due to the greater maturity of solid propulsion technology and its consequent costs, the Sol B/RO Program will be used to conservatively represent the new expendable booster concept in the subsequent A, B and C program cost comparisons.

Configuration weights, a major cost driver, are summarized in Figure 5.1-3. It is readily apparent from these data that all reusable orbiters, except 1-1/2/TA, are the same equivalent size and weight. The 1-1/2/TA orbiter, however, while approximately 20% lighter than the other orbiters, is more complex due to its cross feed design. The CERs used to reflect differences in systems complexity were previously discussed in Section 3.

5.2 Program Costs Comparison

This subsection contains a brief review of the key guidelines, a comparison of total program costs, annual funding, cost per flight, 10-and 15 year program costs, and cost objectives plus a final summary comparison.

5.2.1 Guidelines

The basic A, B, C programs have been costed with the same key ground rules and assumptions. These assumptions, previously covered in Section 2, are summarized in Figure 5.2-1. The Min Risk/FR ($C\text{-}4_{I/II}$) programmatic concept, however, was formulated with a minor variation in ground rules. First, $C\text{-}4_{I/II}$ requires fewer development flight test orbiters than the basic A, B, C programs (i.e., 2 vs 3). Secondly, it relies upon a modified traffic model to attain 445 flights after 10 years of operations. These differences derive from the minimum risk flight development/demonstration approach applied to interim S-1C operations. Interim use of conservative ablative TPS materials for the $C\text{-}4_I$ orbiter's first manned orbital flight (FMOF) plus the available period (3 years) for attaining a full operation configuration has a combined effect of advancing the FMOF date, requiring less vehicles and, at the same time, minimizing the overall development risk.

	1-1/2/TA			Liq B/RO			Sol B/RO			Reus B/O		Min Risk/FR		
					Booster			Booster						
	ORB	SRM	Tanks	ORB	STG 1	STG 2	ORB	STG 1	STG 2	ORB	BSTR	ORB	$BSTR_I$	$BSTR_{II}$
Aero Surfaces	25,884			33880	–	–	33880	–	–	27,951	82,537	27,951	38,000	82,537
Body Structure	42,665			61836	135,000	254,100	61836	17,700	38,000	65,706	148,962	65,706	148,000	148,962
-Incl Main Prop Tnk														
Induced Env. Protect	21,068			32930	200	1,500	32930	200	400	30,177	59,852	30,177	5.000	59.852
Lnch, Recov, & Dock	7,065			7526			7526			7,356	17,217	7,356	3,000	17,217
Propulsion					59,000	120,800		244,700	468,600					
-Rocket Engines	22,669			11013			11013			10,478	47,334	10,478	94,000	47,334
-Air Breathers	-			-			-			-	13,212	-	-	13,212
-Installation	9,454			5736			5736			6,891	25,208	6,891	45,000	25,208
-On-Orbit Tanks	2,701			1961			1961			2,027	-	2,027		-
Orientation Control	4,829			5860			5860			5,794	9,609	5,794		9,609
Hydraulics	5,573			6118			6118			5,333	6,617	5,333		6,617
Other Subsystems	6,679			7210	1,400	100	7210	900	1,800	7,022	7,290	7,022	4,000	7,290
Strongback	-	-	-	-	-	-	-	-	-	-	-	-	83,000	-
Contingency	14,859			17407	9,800	18,900	17407	5,300	10,200	16,873	41,784	10,873	13,000	41,784
Dry Weight	163,446			191476	205,400	397,300	191476	268,800	519,000	185,608	459,622	185,608	433.000	459,622
Crew	400			400	-	-	400	-	-	400	400	400	-	400
Reserves + Residuals	896			1556	37,800	77,600	1556	-	-	1,594	23,464	1,594		23,464
Payload	25,000			25,000	-	-	25,000	-	-	25,000	-	25,000	-	-
Landed Weight	189,742			218432	-	-	218432			212,602	483,486	212,602		483,486
Fly Home Prop	-			-			-			-	22,732	-		22,732

Figure 5.1-3. Concept Weight Breakdown - Costed Point Designs

	1-1/2/TA			Liq B/RO			Sol B/RO			Reus B/O		Min Risk/FR		
					Booster			Booster						
	ORB	SRM	Tanks	ORB	STG 1	STG 2	ORB	STG 1	STG 2	ORB	BSTR	ORB	$BSTR_I$	$BSTR_{II}$
Max Cruise Wt	189,742			218432			218432			212,602	506,218	212,602	–	506,218
Reserves + Residuals	5,462			9554	10,300	20,800	9554			9,756	21,323	9,756	87,000	21,323
On-Orbit Prop	18,932			22105			22105			21,571	-	21,571	-	-
RCS Propellant	3,682			4223			4223			4,246		4,246		
Injection Weight	217,818	159,099	108,644	254314	253,500	495,700	254314	268,800	519,000	248,175	527,541	248,175	520,000	527,541
(± TGT Correct.)	-	-	-	-	(+5,200)	(+21,500)		(-20,200)	(-21,800)	-	-	-	-	
Injection Prop	113,273	1,232,901	1,550,275	491325	1,588,700	3,177,400	491325	1,663,900	3,327,800	485,825	2,402,459	485,825	4,575,000	2,402,459
Lift Off Wt	331,091	1,392,000	1,658,919	745640	1,847,400	3,694,600	745640	1,912,500	3,825,000	734,000	2,930,000	734,000	5,095,000	2,930,000
GLOW	3,382,010			6,287,640			6,483,140			3,664,000		5,829,000/3,664,000		

Figure 5.1-3. Concept Weight Breakdown - Costed Point Designs (Cont)

A-3A, B-2I, C-4		C-4 I/II
100, 220, 365, 445	Number of Operational Flights (4 Basic Models)	445
1 (KSC)	Number of Operational Launch Bases	1 (KSC)
3/2	Number of Development Flight Test Orbiters/Boosters	$2/2_{II}$
3/2 + 2/3 = 5/5	Number of Operational Orbiters/Boosters	$2/2_{II} + 3/3_{II} = 5/5_{II}$
Late CY 77	First Manned Orbital Flight	Early CY 77
100%	Learning Rate for Orbiters and Reusable Boosters	100%
90%	Learning Rate for Drop Tanks	90%
95%	Learning Rate for SRM	95%
Yes	Costs in 1970 Dollars	Yes
Yes	Discounted Costs	Yes
Included	Contractor Effort (Less Fee)	Included
Included	Primary Engine Costs	Included
Included (In Booster)	Airbreather Engine Costs	Included ($C\text{-}4_{II}$ Bstr)
Included	Government-Funded Facilities	Included
	– Launch – Refurbishment	
	– Recovery – Flight Test	
Included	Propellant Costs	Included
Included	Training Costs	Included
Excluded	Government Operations and Test	Excluded
Excluded	Government Management and Technology	Excluded

Figure 5.2-1. Key Costing Assumptions

During the first 3 years of operations, the S-1C launch rate is limited to 3 flights per year (see Figure 5.2-2). Hence, the Min Risk/FR traffic model uses a higher flight rate over the next 5 years than the standard model.

The same operational fleet size is used for all programs (i.e., 5 orbiters and reusable boosters for 445 flights during 10 years of operations). Total fleet size is comprised of converted flight test vehicles plus additional production flight articles. Vehicle allocation of expendable and reusable flight articles is summarized in Figures 5.2.-3 and 5.2-4.

5.2.2 Total Program Costs

Total program costs, for competitive space shuttle concepts, are presented in Figure 5.2-5. These costs are further sub-divided into non-recurring DDT&E and recurring production and operations for 100, 220, 365, and 445 total flights. As expected, concepts with expendable hardware are the least costly to develop and the most costly to maintain high flight rate operations. The expendable booster concepts 1-1/2 TA, Liq B/RO and Sol B/RO can be developed for about 2/3 of the cost needed for the Reus O/B. As a result, at the lowest traffic rate of 100 total flights, the expendable booster concepts retain a $2.0B advantage in total program costs. At the higher traffic rates, the difference in total program costs lessens. However, at 445 total flights, 1-1/2 TA is still $0.5B less than the Reus O/B. The Min Risk/FR program has both higher DDT&E and total program costs than the Reus O/B. These relationships are illustrated further by the comparative chart shown in Figure 5.2-6.

A detailed comparison of program DDT&E and first unit costs are presented in Figures 5.2-7 and 5.2-8. Development and manufacture of the orbiter subsystems is noted to vary with the degree of systems complexity within each concept (e.g., cross feed in 1-1/2 TA orbiter main propulsion). Related production and operations costs for 445 flights are detailed in Figure 5.2-9.

5.2.3 Annual Funding

Comparative annual funding requirements are presented in Figure 5.2-10. Except for the Min Risk/FR, the remaining programs are constrained to a 7 year development period. Consequently, the program with the higher DDT&E cost

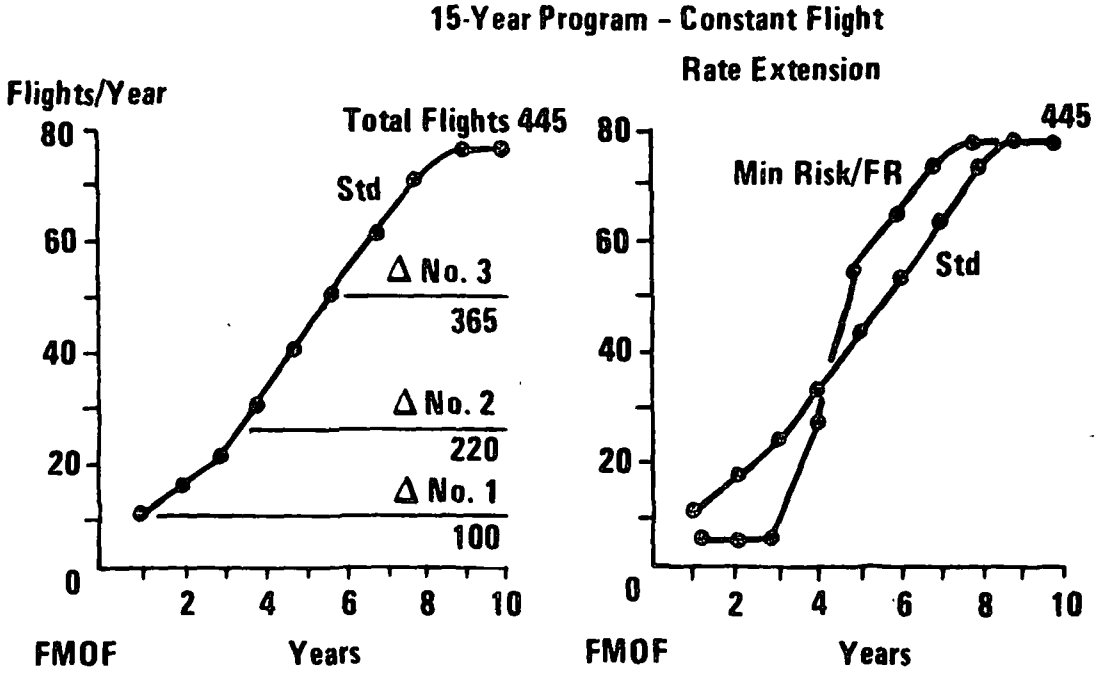


Figure 5.2-2. Traffic Models

	A-3A		B-21		C-4	
	Orb.	Tank/SRM	Orb.	SRM-Bstr	Orb.	Bstr
Test Operations						
Structural Art.	0.75	1/0	0.75	--	0.75	0.75
Propulsion Art.	0.75	2/2	0.75	--	0.75	0.75
Booster Dummy Orb.	--	--	0.2	--	--	--
Flight Test Vehicle	3	14/7	3	8	3	2
Flight Operations						
Flight Test Vehicle Conversion	4	--	3	--	4	2
10-Yr Total Fleet - 445 Flights	5	890/445	5	445	5	5
15-Yr Total Fleet - 820 Flights	9/5*	1640/820	9/6*	820	9/6*	9/6*

*No Vehicle Life Limit

Figure 5.2-3. Vehicle Allocation

	Reus O/B		Min Risk/FR		
	Orb.	Bstr	Orb	S-1C	Bstr
Test Operations					
Structural Art.	0.75	0.75	0.75	STBK	0.75
Propulsion Art.	0.75	0.75	0.75	–	0.75
Flight Test Vehicle	3	2	3	2	2
Flight Operations					
Flight Test Vehicle Conversion				–	
10-Yr Total Fleet - 445 Flights	5	5	6	9	6
15-Yr Total Fleet - 820 Flights	9/6*	9/6*	9/6*	–	9/6*

*No Vehicle Life Limit

Figure 5.2-4. Vehicle Allocation

	1 1/2 TA	Liq B/RO	Sol B/RO	Reus O/B	Min Risk/FR
DDT & E	4.361	4.614	4.276	6.901	7.076
Production					
100	.964	.778	1.454	.431	
220	1.957	1.499	3.005	.431	
365	3.268	2.546	4.973	1.021	
445	4.110	3.156	6.188	1.612	2.185
Operations					
100	.416	.839	.485	.587	
220	.631	1.249	.741	.903	
365	.844	1.794	.941	1.273	
445	.998	2.131	1.105	1.475	1.546
Program Total					
100	5.741	6.231	6.215	7.919	
220	6.949	7.390	8.022	8.235	
365	8.473	8.954	10.190	9.195	
445	9.469	9.901	11.569	9.988	10.807

Figure 5.2-5. Program Cost Summary - 10 Years, Billions $

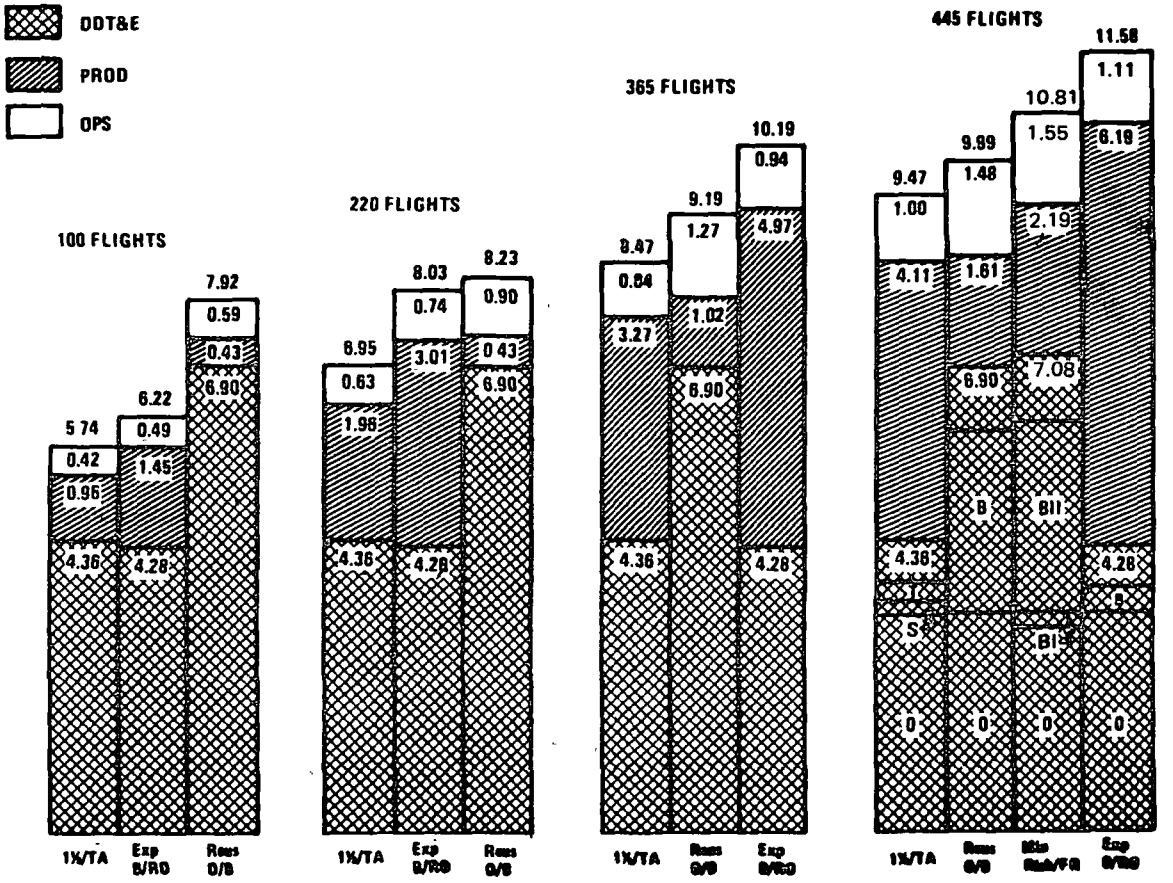


Figure 5.2-6. Concept Comparison, Total Program Cost
For 10 Years, No Discount

	1 1/2/TA			Liq B/RO		Sol B/RO		Reus O/B		Min Risk/FR		
	Orb	SRM	Tanks	Orb	Bstr	Orb	Bstr	Orb	Bstr	Orb	$Bstr_1$	$Bstr_{11}$
Structure	206.1	107.0	163.3	235.7	245.0	235.7	140.0	230.3	551.9	230.3	50.2	551.9
Main Tanks	114.4			117.0		117.0		116.1	154.0	116.1		154.0
TPS	146.0			120.0		120.0		120.0	112.0	120.0		112.0
Main Prop.	50.0			32.2		32.2		32.1	36.7	32.1		36.7
Air Breathers	–			–		–		–	100.0	–		100.0
OMS	111.0			111.0		111.0		111.0	–	111.0		–
APS/TVC	212.0			224.6		224.6		222.8	74.2	222.8		74.2
Avionics	554.8			520.0		520.0		520.0	339.0	550.0		339.0
Power	52.0			50.9		50.9		50.9	21.0	50.9		21.0
ECLSS	60.0			60.0		60.0		60.0	14.0	60.0		14.0
Interstage	–			–		–		–	–	–	6.2	–
Sustaining Engineering	–	–	–	–	–	–	–	–	–	50.0	–	100.0
Grnd Test Hdwr	287.6	8.0	16.3	302.3	18.2	302.3	–	298.9	468.4	299.8	–	468.4
Flt Test Veh	632.7	28.0	76.3	665.0	99.1	665.0	146.9	657.5	692.6	441.0	99.6	692.6
Grnd Test Ops & Supt	38.3	–	2.7	37.9	52.4	37.9	–	33.0	46.7	20.0	11.5	27.5
Grnd Test Fac	12.1	–	0.5	12.0	20.5	12.0	–	9.2	17.5	12.0	1.0	18.2
Mfg Fac	15.7	0.4	16.6	16.8	15.6	16.8	4.0	16.8	24.9	16.2	–	24.9
Veh Supt Equip	107.0	10.0	25.7	109.7	86.2	109.7	47.3	107.0	71.4	108.6	–	71.4
Vehicle Total	2599.7	153.4	301.4	2615.1	537.0	2615.1	338.2	2585.6	2724.4	2440.8	168.5	2805.8
Main Engine	656.5	–	–	658.6	110.0	658.6	–	654.7	–	654.7	21.0	10.0
Flt/Com Test Ops & Supt	131.8			187.8		157.5		159.0		110.7/83.0		
Flt/Com Test Fac/GSE	122.1			85.6		117.8		149.5		63.1/75.1		
Sys Int/Mgt	396.5			419.4		388.7		627.3		350.9/292.4		
Total DDT&E	4361			4614		4276		6901		7076.0		

Figure 5.2-7. Program Cost Comparison, DDT&E

	1½/TA			Liq B/RO		Sol B/RO		Reus O/B		Min Risk/FR		
	Orb	SRM	Tanks	Orb	Bstr	Orb	Bstr	Orb	Bstr	Orb	$Bstr_I$	$Bstr_{II}$
Vehicle												
Structure	59.7			74.5		74.5		72.7	123.2	72.7		123.2
Main Tanks	18.0			25.6		25.6		24.9	40.0	24.9		40.0
TPS	2.8			4.9		4.9		4.9	8.7	4.9		8.7
Main Propulsion	12.5			7.4		7.4		7.4	16.1	7.4		16.1
Air Breathers	–			–		–		–	4.5	–	35.9	4.5
OMS	3.8	2.54	10.68	3.8	8.0	3.8	14.5	3.8	–	3.8	5.8	–
APS/TVC	5.5			6.6		6.6		6.5	11.7	6.5		11.7
Avionics	66.7			64.0		64.0		64.0*	61.0	65.0		61.0
Power	5.4			5.4		5.4		5.4*	3.6*	5.4		3.6
ECLSS	1.8			1.8		1.8		1.8*	0.7*	1.8		0.7
Interstage	–			–		–		–	–	–	1.3	–
Propellant		1.4			1.1		3.5					
Vehicle Total	–	3.94	–	–	9.1	–	18.0	–	–	–	–	–
Vehicle Total W/O Prop.	176.3	2.54	10.68	194.0	8.0	194.0	14.5	191.5	269.5	192.5	43.0	269.5
Main Engine	14.9	–	–	7.5	4.1	7.5	–	7.4	42.8	7.4	9.0	42.8
Total Vehicle and Eng Dry	191.2	2.54	10.68	201.5	12.1	201.5	14.5	198.9	312.3	199.9	52.0	312.3

Costs in Millions

*Costs Provided by NASA

Figure 5.2-8. First Unit Cost Summary, $M

	1½/TA			Liq B/RO		Sol B/RO		Reus O/B		Min Risk/FR		
	Orb	SRM	Tanks	Orb	Bstr	Orb	Bstr	Orb	Bstr	Orb	$Bstr_I$	$Bstr_{II}$
Flight Articles	420.6	1229	2032	443.3	2385.9	443.3	5213.0	437.6	1031	659	324.4	1031
Test Veh Conver	38.5	–	–	74.8	–	74.8	–	29.9	37	30	–	37
Prod Fac (Addl)	–	75	119	–	101.9	–	162.5	–	–	–	–	–
Sys Int/Mgt	22.9	65.2	107.5	25.9	124.4	25.9	268.8	23.3	53.4	34.4	16.2	53.4
Veh Total	482.0	1369	2258.5	544.0	2612.2	544.0	5644.3	490.9	1121	723.4	340.6	1121.4
Production Total	4110			3156		6188		1612		2185.4		
Ops & Support	369.1			954.5		458.4		349.1		140/340.1		
Materials	565.0			1009.6		544.9		1024.8		30.8/930.		
Ops Fac/GSE (Addl)	16.1			65.5		49.3		30.9		2.7/28.2		
Sys Int/Mgt	47.5			101.4		52.6		70.2		8.7/64.9		
Operations Total	998			2131		1105		1475		1545.4		
DDT&E Total	4361			4614		4276		6901		7076.0		
Total Program	9469			9901		11,569		9988		10807		

Figure 5.2-9. Program Cost Comparison, Production/Operations, 445 Flights

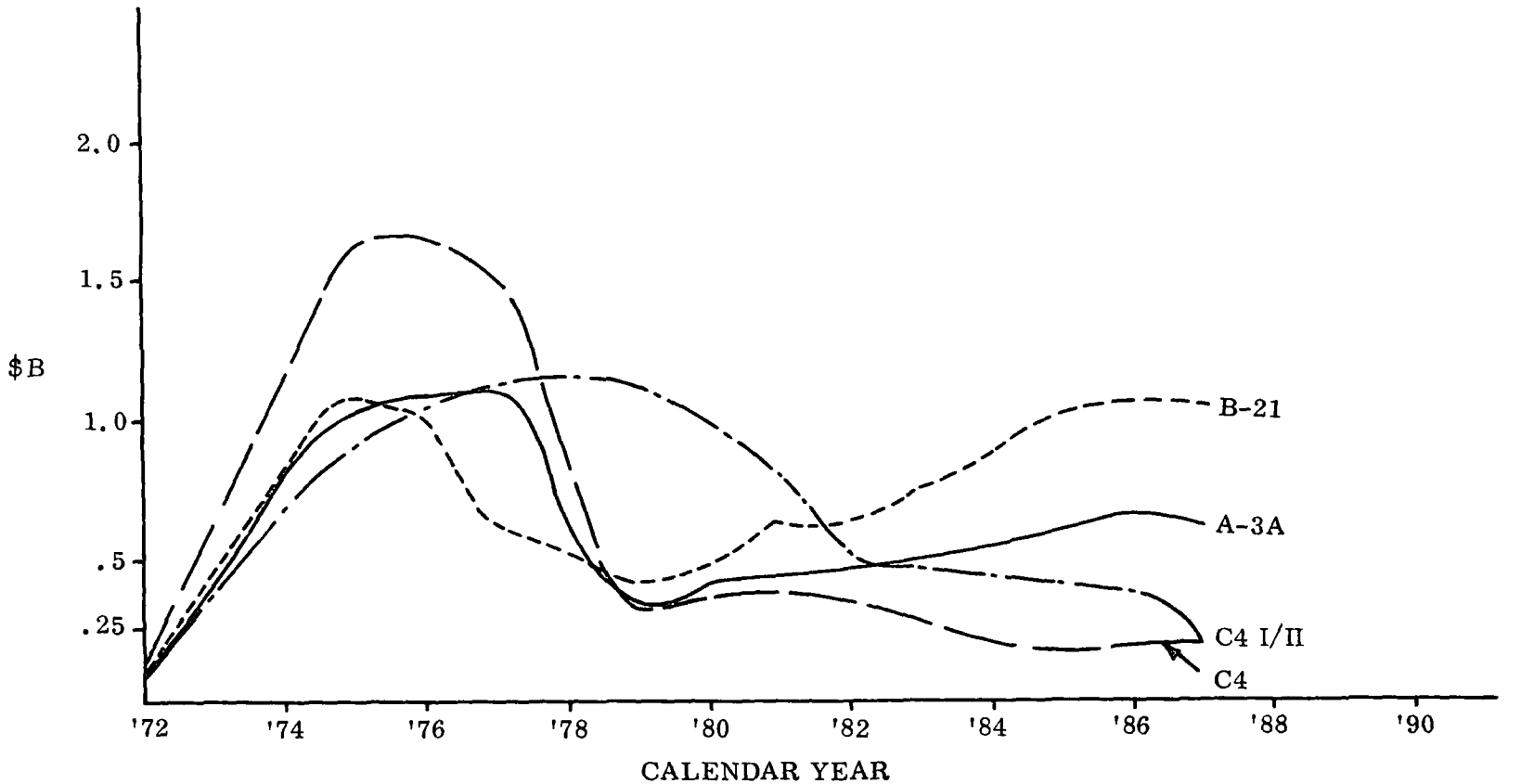


Figure 5.2-10. Annual Program Costs-No Discounting

(i.e., Reus O/B at $6.90B) also requires the highest annual funding. The peak funding for Reus O/B ($1.64B) occurs in 1975. Although the Min Risk/FR program has the highest DDT&E, it does not follow this trend since the total development period is 3 years longer. Therefore, the peak annual funding needed by the expendable booster concepts and the Min Risk/FR program are somewhat lower ($1.1B).

5.2.4 Cost Per Flight

Comparative shuttle launch costs are shown in Figure 5.2-11. These costs reflect the normal operating expenses that must be borne for each launch. The equivalent cost of an expendable Titan III D launch vehicle ($12.0M) is about four times as costly to operate as the Reus O/B. However, unlike the shuttle, the T-IIID is limited to one-way payload delivery and total payload loss in event of abort. Thus, the effective cost of the Titan should be adjusted to compensate for its limitations relative to the shuttle. Accounting for conservative 5% loss in both launch vehicle and payload due to abort, plus a 1/3 loss in payload reusability, due to one-way delivery, effectively increases the T-IIID cost per flight to $24.1M. This is eight times the cost of operating the Reus O/B, which can also provide crew transport.

Shuttle cost per flight can also be examined relevant to amortization of the production vehicles, operational fleet, or total program. Figures 5.2-12 and 5.2-13 show that the Reus O/B has the lowest cost per flight for all but the amortized total program value. The cost per flight breakdown, presented in Figure 5.2-14, denotes the basic factors used for each type of cost per flight. It is readily seen that expendable production articles contribute over 50% of the nominal launch costs in each concept except Reus O/B and FR.

5.2.5 10 Year and 15 Year Costs

Cumulative program costs, extending through the first 10 years of operations, are presented in Figure 5.2-15. With no discounting applied, cumulative costs of the Sol B/RO program exceed Reus O/B program costs after the 8th year of operations. As noted previously, 1-1/2 TA costs remain lower than Reus O/B costs for the entire 445 flights. A cross-over between 1-1/2 TA and Reus O/B costs can be attained, however, by extending the operational period from 10 to 15 years.

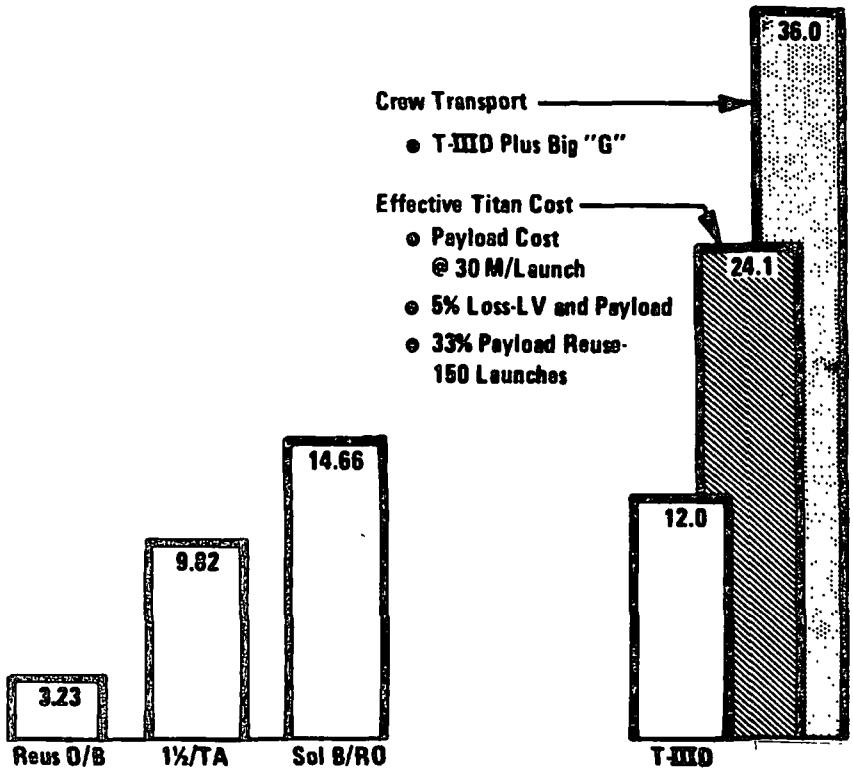


Figure 5.2-11. Concept Comparison, Operational Cost/Flight, 445 Flights-No Amortization

	1½/TA	LIQ B/RO	Sol B/RO	Reus O/B	Min Risk/FR
Operations and Expendables	9.82	10.26	14.66	3.23	57.5/3.1
Amort Production	10.38	11.49	15.89	6.79	---
Amort Operational Fleet	10.97	12.59	15.99	9.03	---
Amort Total Program	21.28	22.25	25.98	22.44	---

Figure 5.2-12. Cost/Flight, 445 Flights

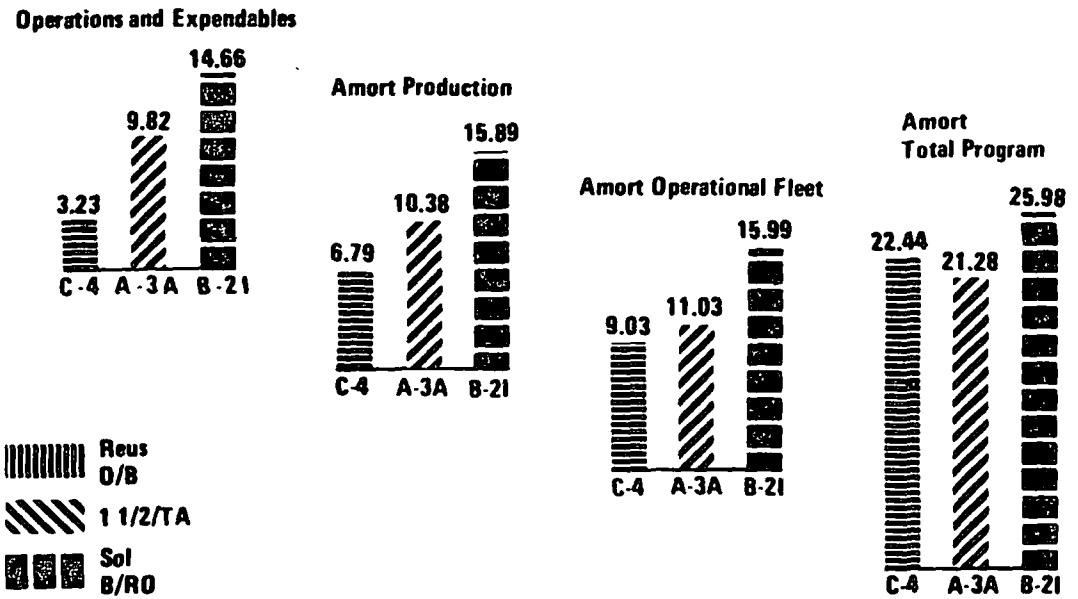


Figure 5.2-13. Cost/Flight, 445 Flights, $M

	1 1/2/TA	Liq B/RO	Sol B/RO	Reus O/B	Min Risk/FR
Prod. Expend./445 Flt	7.34	5.36	11.71	–	36.0/-
Orb. Refurb Matl/Flt	.36	.60	.60	.59	.60/.60
Bstr Refurb Matl/Flt	–	–	–	.79	-/.79
Fac/GSE Refurb Matl/445 Flt	.55	.52	.54	.45	3.33/.32
Propellants/Flt	.27	1.15	.08	.47	.27/.47
Oper & Support/445 Flt	.83	2.14	1.03	.78	14.44/.78
Sys Int/Mgt/Flt	.47	.49	.70	.15	2.75/.14
Cost/Flt (Oper & Expend)	9.82	10.26	14.66	3.23	57.5/3.10
Tech Veh. Conv./445 Flt	.04	.17	.17	.09	
Prod. Flt Veh/445 Flt	.50	1.00	1.00	3.30	
Sys Int/Mgt	.02	.06	.06	.17	
Cost/Flt (Amort Prod.)	10.38	11.49	15.89	6.79	
Ops Cost/Flt	9.82	10.26	14.66	3.23	
Prod. Veh/100 Flt	1.15	2.33	2.33	5.80	
Cost/Flt (Amort Op Fleet)	10.97	12.59	15.99	9.03	
Cost/Flt (Amort Prog)	21.28	22.25	35.98	22.44	

Figure 5.2-14. Cost/Flight, 445 Flights, $M

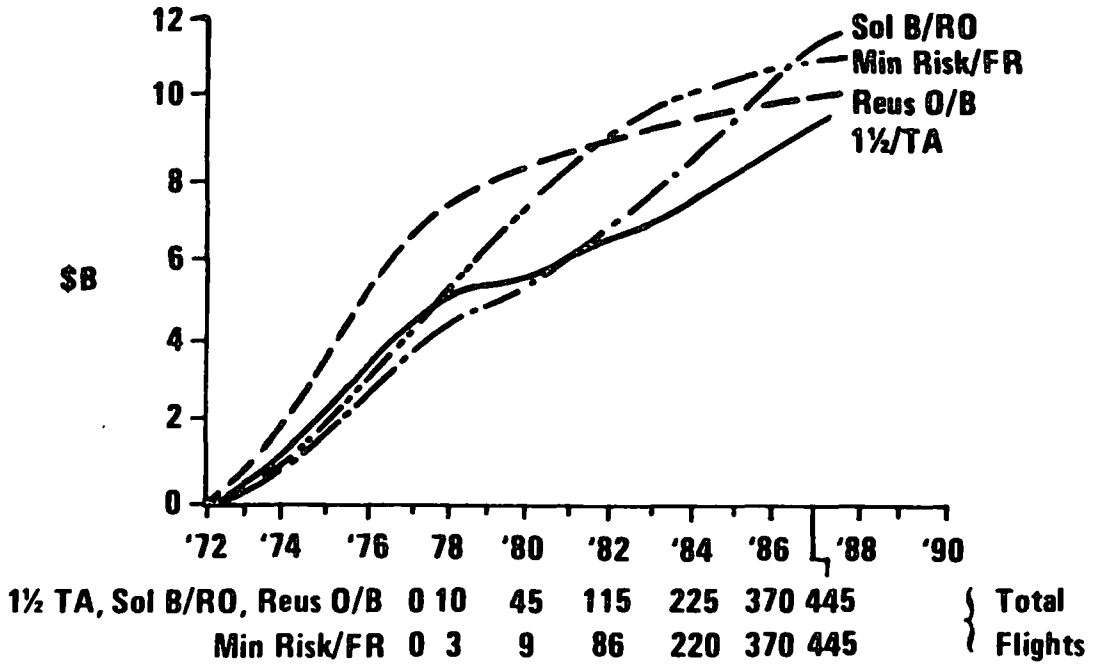


Figure 5.2-15. Concept Comparison Cumulative Costs, 10 Years, No Discounting

In the Reus O/B program, 5 orbiters and 5 boosters are nominally required for 445 flights in 10 years. The effect of extending the operational period another five years, at the maximum flight rate, adds four more orbiters and boosters to the operational fleet. Additional vehicles are needed to comply with the 100 flight vehicle life constraint. The net affect of adding these additional vehicles is illustrated in Figure 5.2-16. Total program costs will increase to $13.3B at 15 years. However, if the 100 flight vehicle life limit is raised, permitting longer vehicle usage, lower total costs will be incurred. For example, if the operational requirements attendant with 820 flights in 15 years, can be handled with a fleet of six orbiters and boosters, the 15 year cost could be held to $11.8B.

Cumulative program costs, extending through 15 years of operations, are presented in Figure 5.2-17. Based on the 100 flight limit on vehicle life, the total cost of the Min Risk/FR, 1-1/2 TA and Reus O/B are $14.2B, $13.4B and $14.3B respectively. By relaxing the vehicle flight constraint, the costs of the 1-1/2 TA, Min Risk/FR, and Reus O/B interchange and become lower at $12.8B, $12.6B and $11.8B respectively.

When discounting is applied to these programs, the present value of the expendable booster concepts are enhanced relative to the Reus O/B or Min Risk/FR programs. For example, 5% discount applied to 10 year program costs for the 1-1/2 TA, Sol B/RO, Min Risk/FR and Reus O/B (see Figure 5.2-18) shows their present value to be $5.8B, $6.6B, $6.7B, and $6.8B, respectively. The present value of the corresponding 10 year costs, at 10% discount, are shown in Figure 5.2-19.

Figure 5.2-20 illustrates the present value of 10 year program costs over a range of discount rates. The effects of 5 and 10% discounting on 15 year program costs are also shown in Figures 5.2-21 and 5.2-22.

For a complete evaluation of the effect of discount rates on present value, the effect of payload benefits should be included. However, this was beyond the scope of the present study.

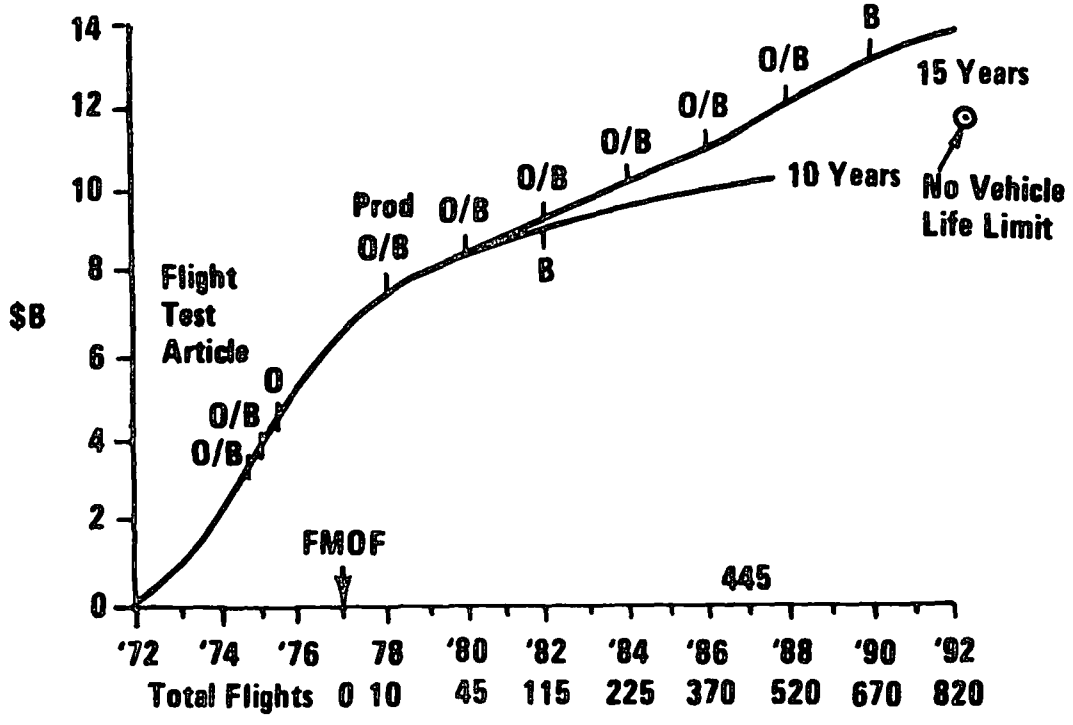


Figure 5.2-16. Reusable O/B Cumulative Costs, 10 and 15 Years - No Discounting

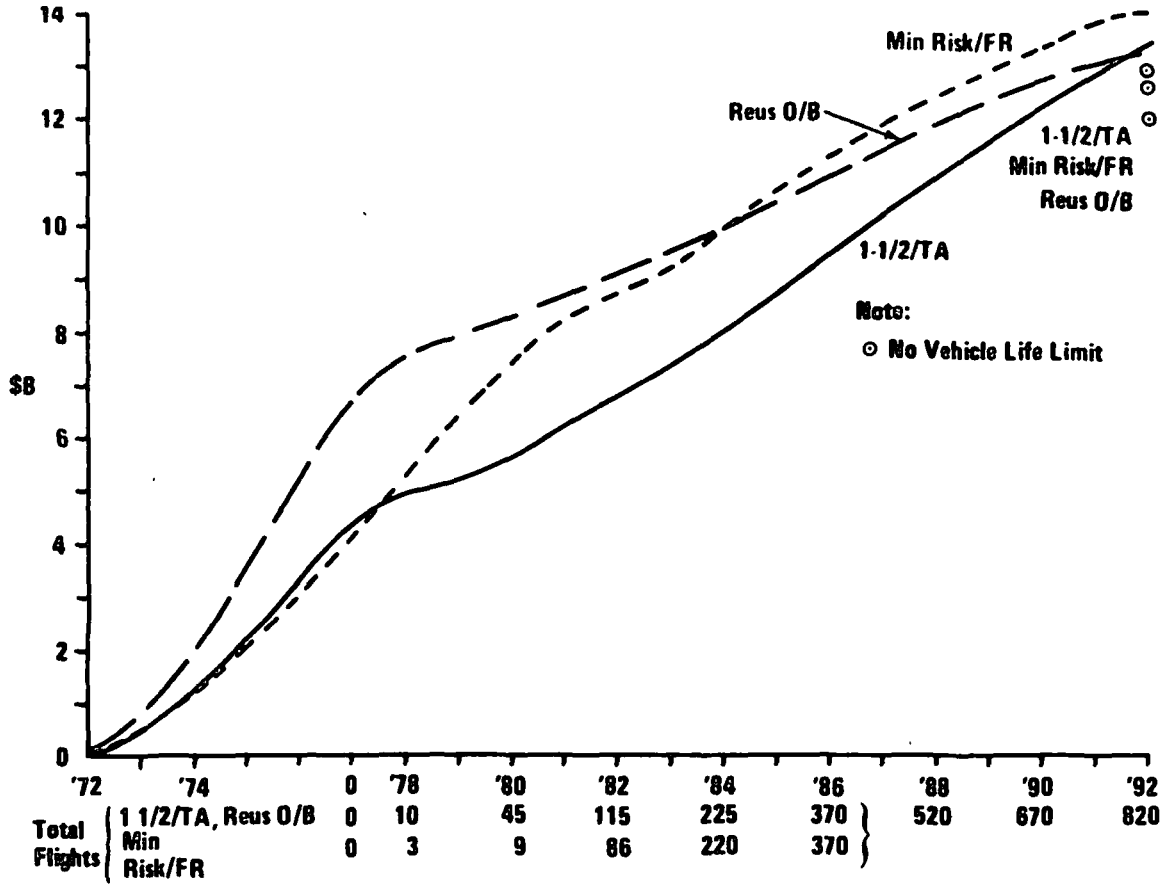
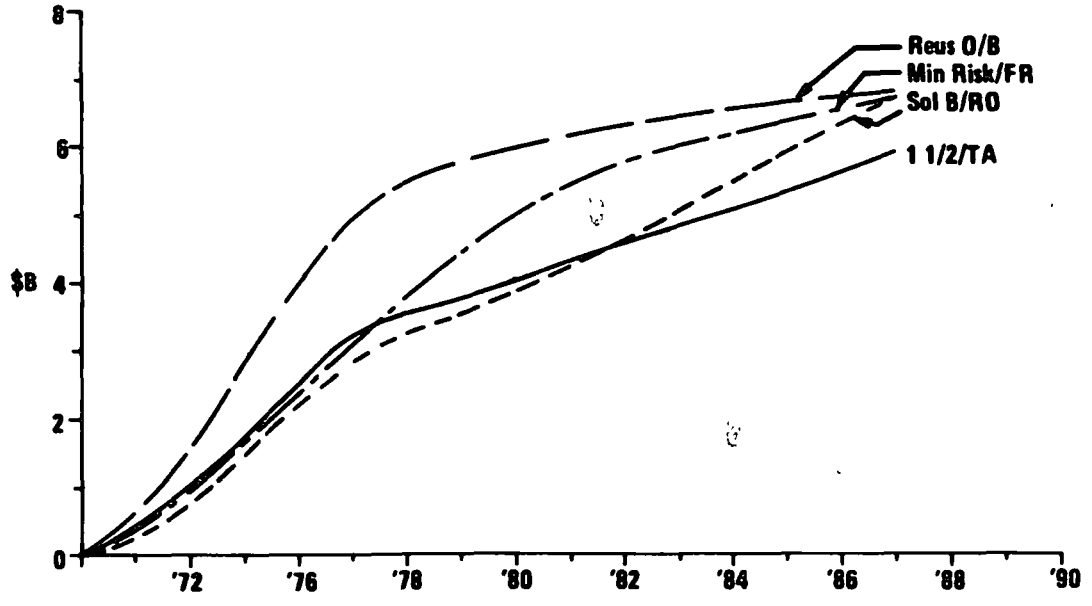
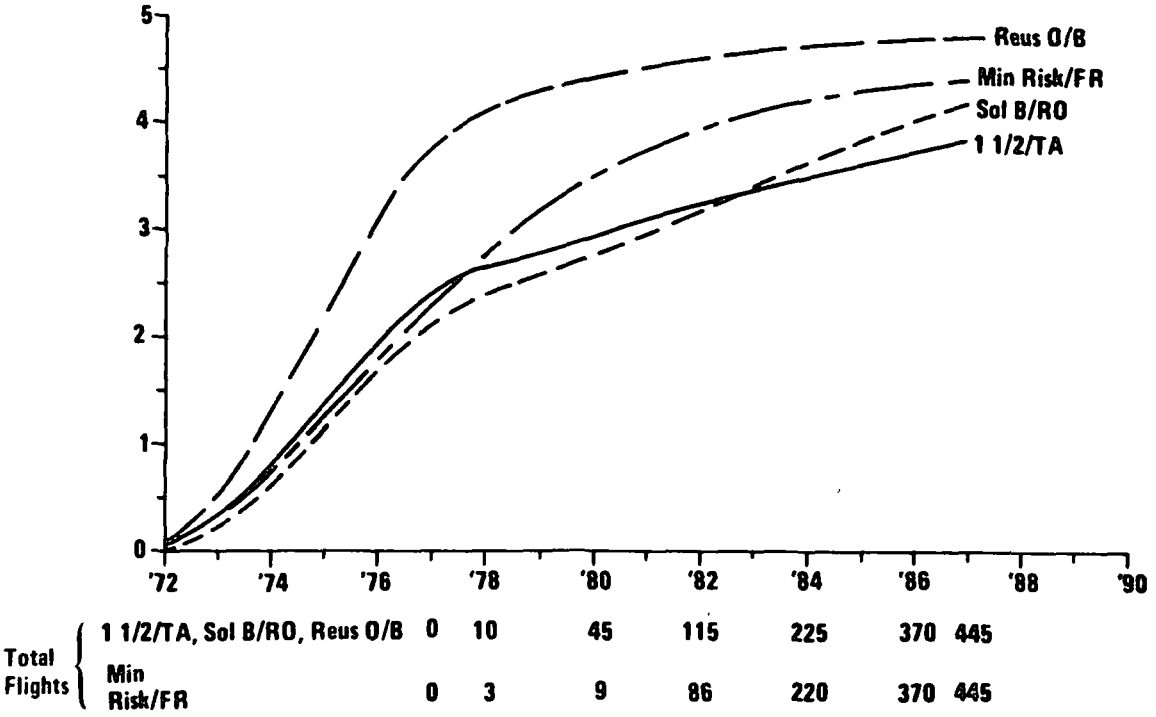


Figure 5.2-17. Concept Comparison, Cumulative Costs, 15 Years - No Discounting



Total Flights								
	1 1/2/TA, Sol B/RO, Reus O/B	0	10	45	115	225	370	445
	Min Risk/FR	0	3	9	86	220	370	445

Figure 5.2-18. Concept Comparison, Cumulative Costs, 10 years - 5% Discount



Total Flights	'72	'74	'76	'78	'80	'82	'84	'86	'88	'90
1 1/2/TA, Sol B/RO, Reus O/B	0	10	45	115	225	370	445			
Min Risk/FR	0	3	9	86	220	370	445			

Figure 5.2-19. Concept Comparison, Cumulative Costs, 10 Years, 10% Discount

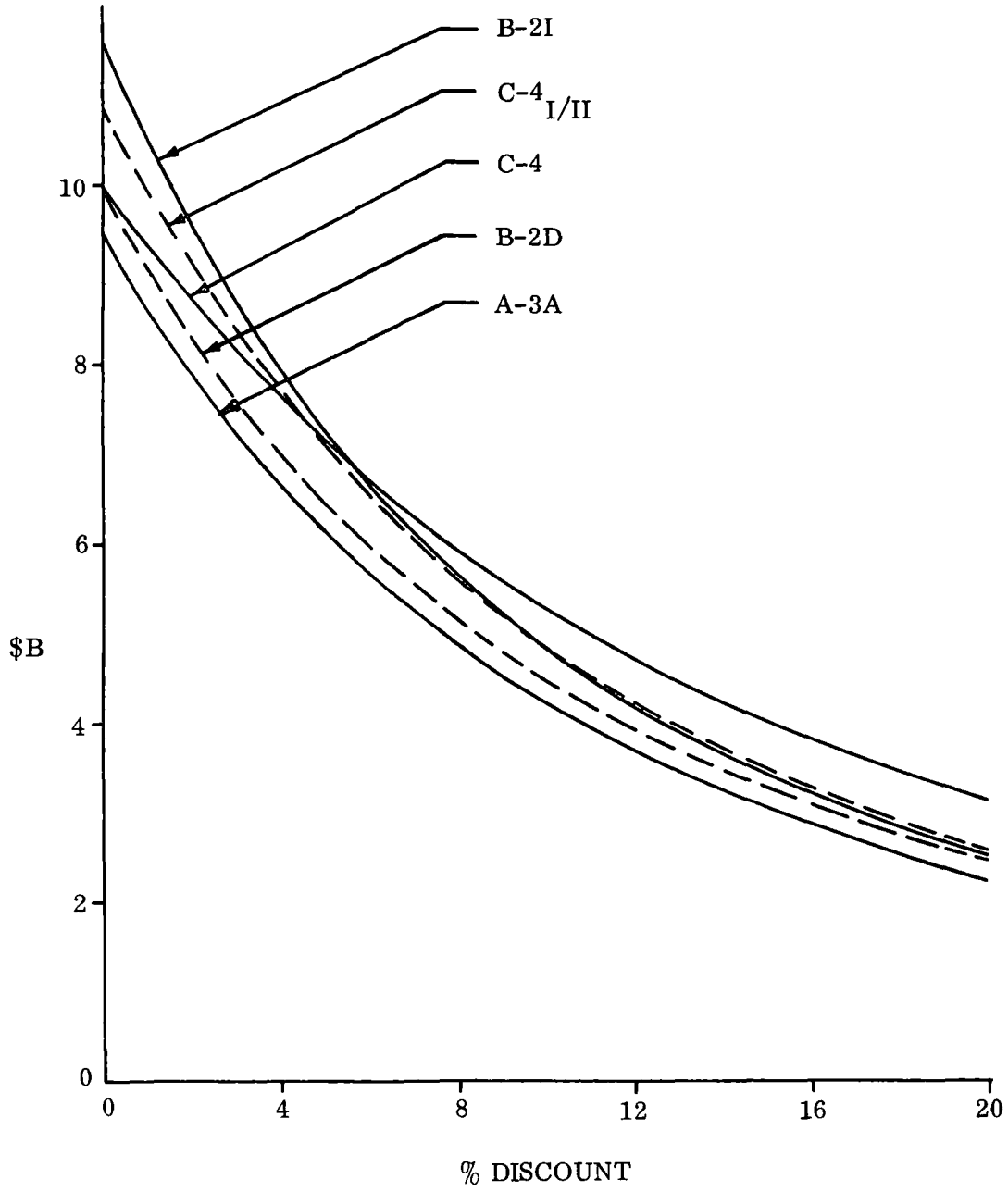
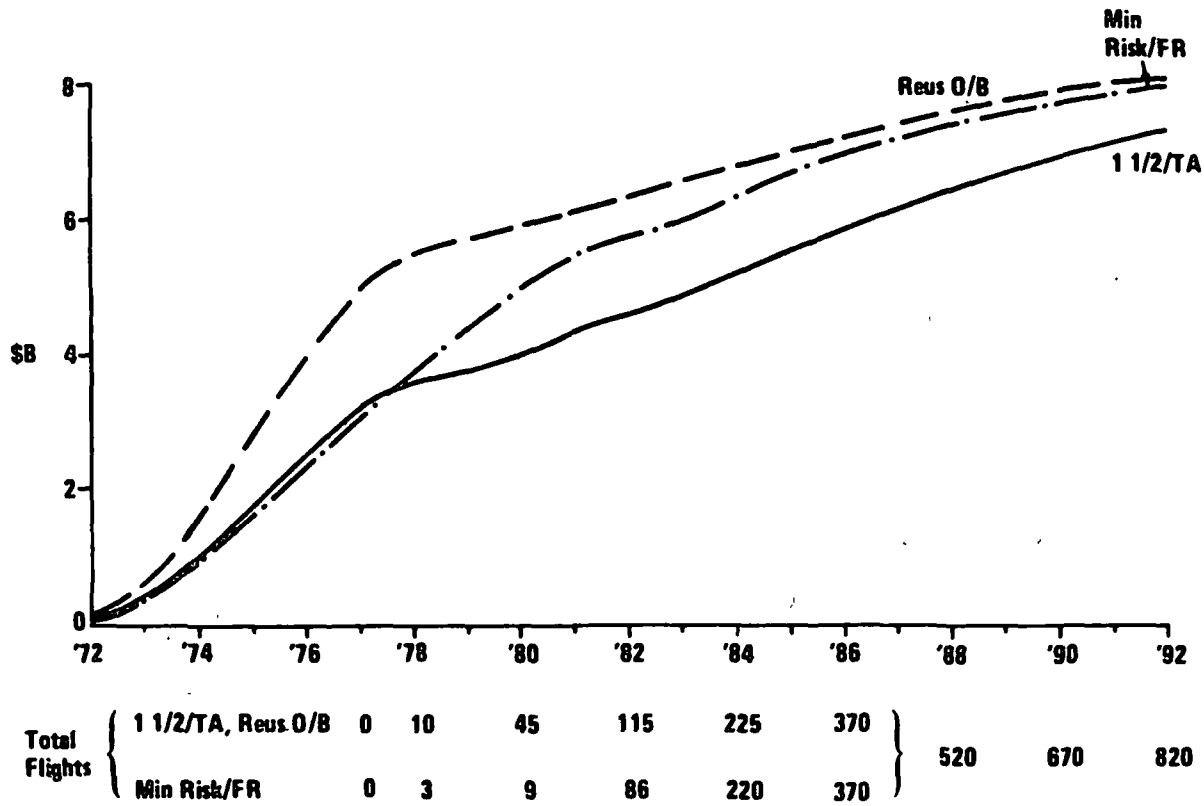


Figure 5.2-20. Present Value Program Cost Comparison, 445 Flights - 10 Years



Total Flights		'72	'74	'76	'78	'80	'82	'84	'86	'88	'90	'92
	1 1/2/TA, Reus O/B	0	10	45	115	225	370	520	670	820		
	Min Risk/FR	0	3	9	86	220	370					

Figure 5.2-21. Concept Comparison, Cumulative Costs, 15 Years - 5% Discount

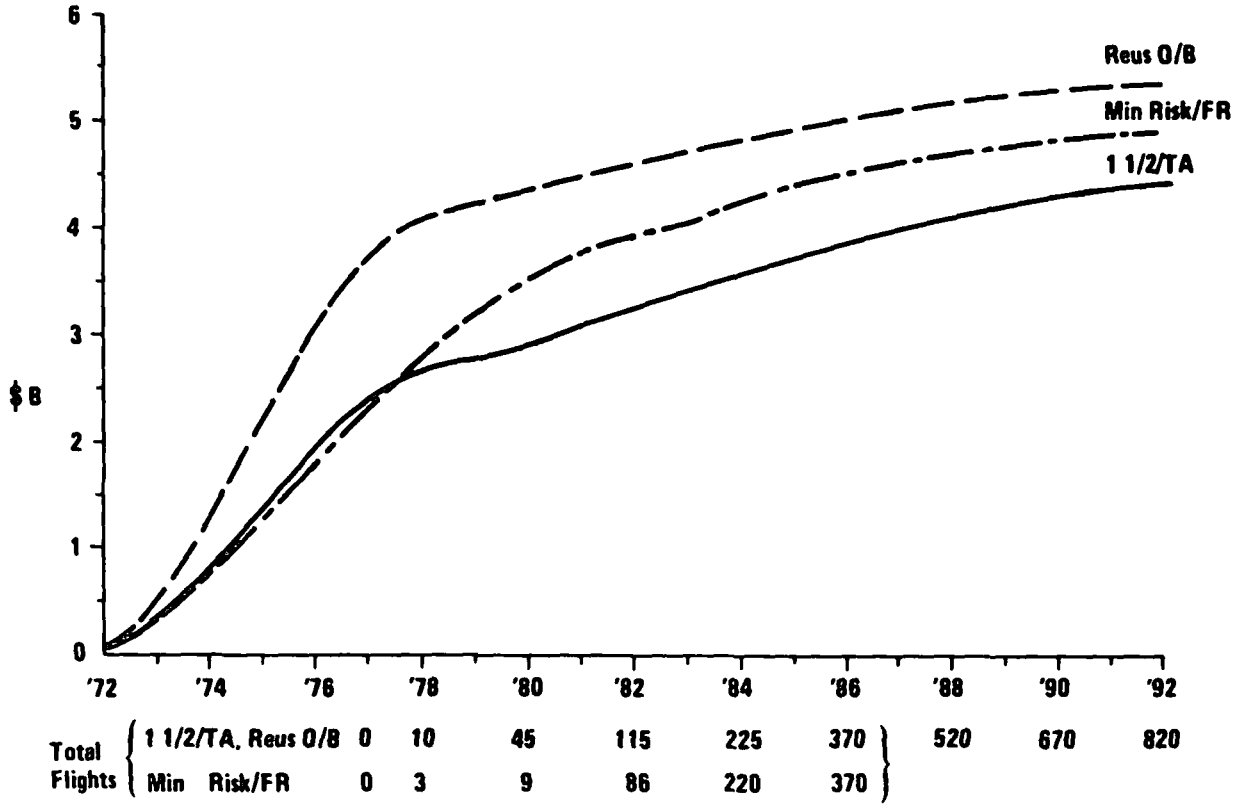


Figure 5.2-22. Concept Comparison, Cumulative Costs, 15 Years - 10% Discount

5.2.6 Cost Objectives

Although presently not required during our Phase A study, comparable cost objective values are shown for each concept in Figure 5.2-23. Consistent with the definition of Cost Objective 1 (i.e., DDT&E to FMOF), the 1-1/2 TA, Sol B/RO and Min Risk/FR programs are each within the NASA $4.5B cost bogey. However, on a total program basis, all programs exceed the NASA equivalent $7.2B cost bogey.

The procedure used to derive Cost Objectives 1 and 2 for each concept is detailed in Figure 5.2-24.

5.2.7 Cost Summary

The comparison of alternate space shuttle program costs has been directed toward answering the following questions.

- Which is the lowest cost 10 year program, discounted and undiscounted?
- Which is the lowest cost long term (15 year) operations program?
- Which program holds peak annual funding to one billion dollars?
- Which program concept costs the least to develop?
- Which concept affords the lowest operational cost per flight?
- Which concepts meet NASA's $4.5B cost bogey for Cost Objective 1?

Comparative answers to these questions are summarized in Figure 5.2-25.

As noted, the 1-1/2 TA program is characterized by the lowest 10 year program cost (445 flights); the lowest 10 year discounted program cost (10%); holds peak annual funding to approximately $1B; and meets NASA Cost Objective 1. These economic advantages stem from the relatively low 1-1/2 TA DDT&E costs attendant with developing a single reusable system. However, since 1-1/2 TA is not fully reusable, neither its operational costs per flight nor its long term total program costs will ever be as attractive as those of the Reus O/B.

The higher DDT&E in the Reus O/B program, caused by parallel development of reusable orbiter and booster necessitates higher peak annual funding and higher cumulative DDT&E costs to FMOF. The phase development approach in the Min/Risk FR

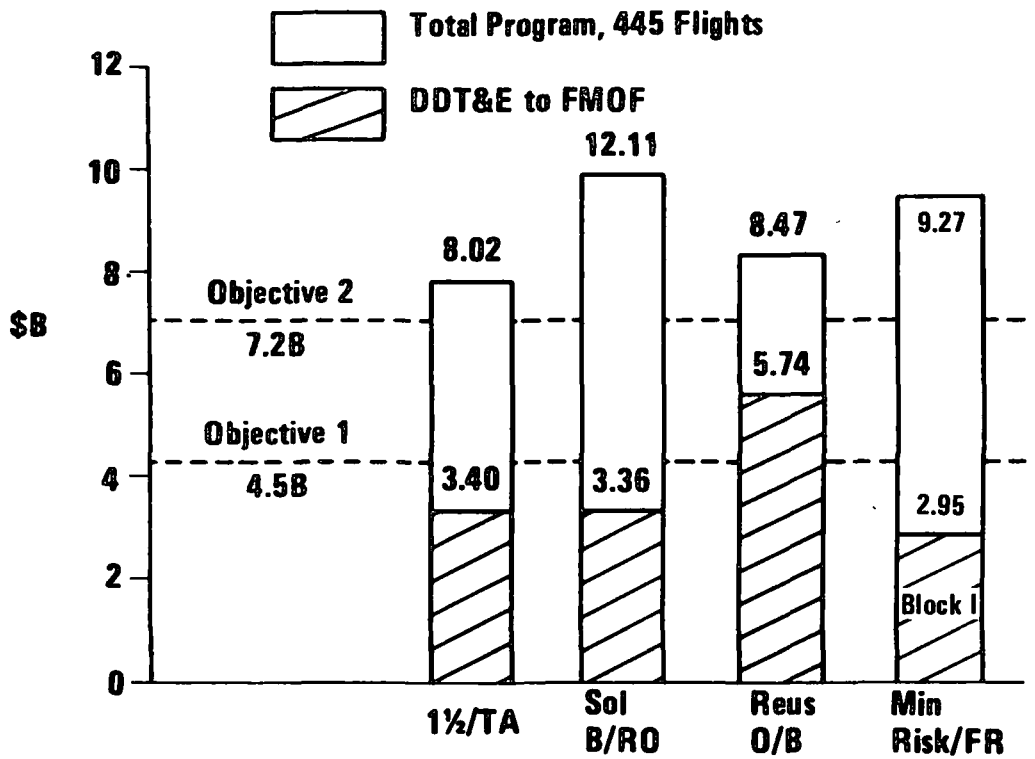


Figure 5.2-23. Concept Cost Objective Comparison

	1½/TA	Liq B/RO	Sol B/RO	Reus O/B	Min Risk/FR
Cost Objective 1					
Main Eng DDT&E	656	659	659	655	655
Main Eng Veh Test Hdwr	69	36	36	208	91
Mfg/Test Fac/GSE	167	151	151	218	29
Test Ops-Base Maint	62	97	66	76	129
Post FMOF Test Ops	6	7	7	6	11
Objective 1 Delta	960	950	919	1163	915
Total DDT&E	4361	4614	4276	6901	3860
DDT&E to FMOF	3401	3664	3357	5738	2945
Cost Objective 2					
Main Eng DDT&E	656	659	659	655	665
Main Eng Veh Test Hdwr	69	36	36	208	250
Main Eng Prod Veh Hdwr	30	17	17	100	200
Mfg/Test Fac/GSE	167	151	151	218	72
Prod Fac (Addl)	194	102	162	–	–
Ops Fac/GSE (Addl)	16	66	49	31	–
Test Ops-Base Maint	62	97	66	76	108
Ops-Base Maint & Support	246	636	306	232	241
Objective 2 Delta	1440	1764	1446	1520	1536
Total Prog (445 Flt)	9469	9911	11,558	9988	10807
Total Prog Objective	8029	8147	10,112	8468	9271

Figure 5.2-24. Program Cost Objectives, $M

	1½/TA	Sel B/RO	Reus O/B	Min Risk/FR
Cost				
Lowest 10 Yr Program Cost (445 Flights), $B	9.5	11.6	10.0	10.8
Lowest 10 Yr Disc Program Cost (10%), $B	3.8	4.4	4.8	4.4
Lowest Long Run (15 Yr) Program Cost(620)*, $B	12.8	16.8	11.8	12.6
Holds Peak Annual Funding, $1B	1.1	1.1	1.6	1.1
Lowest DDT&E, $B	4.4	4.3	6.9	7.1
Assures Capture of Titan Traffic, $M/Flt	9.8	14.7	3.2	58→3.1
Meets NASA Cost Objective 1 (4.5B)	3.4	3.4	5.7	2.9*

*No Vehicle Life Limit

Figure 5.2-25. Concept Comparison

program offers one way of gaining a fully reusable system with lower annual funding and an early FMOF date. Specifically the Min Risk/FR program is characterized by its ability to hold annual funding to approximately $1B, assure low operational cost per flight to capture Titan traffic, and retain DDT&E costs to FMOF within NASA's bogey for Cost Objective 1.

Section 6
PROGRAMMING ALTERNATIVES

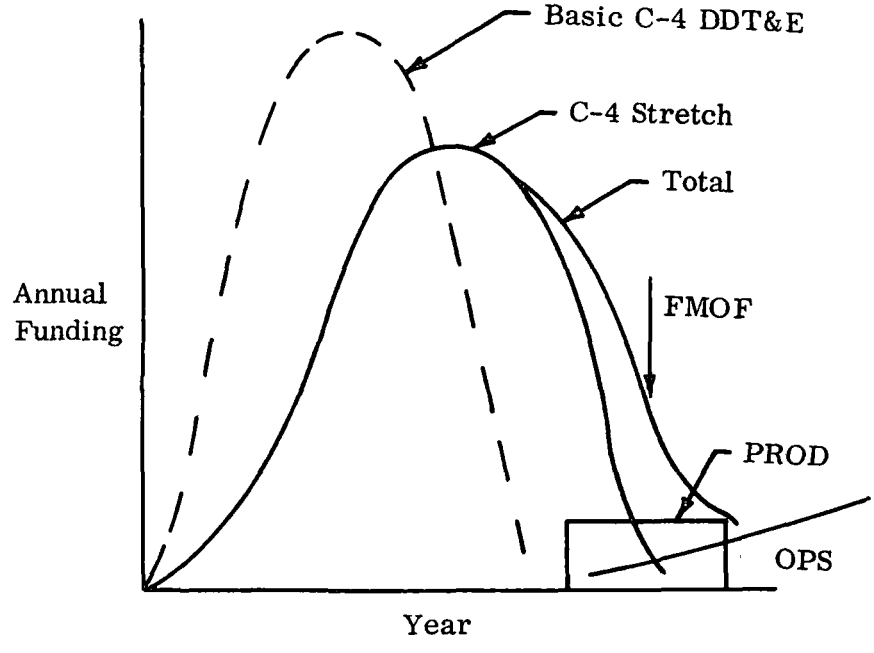
Results of many current studies have indicated that the peak annual funding required to achieve the fully reusable Space Shuttle with a First Manned Orbital Flight (FMOF) in the latter part of 1977, may exceed the probable available annual budget. In fact, the achievement of reduced annual funding requirements in the early years of the shuttle program may well be more important than the achievement of a minimum cost total program. Also, the achievement of the primary objectives of the space shuttle program requires the successful development of two mutually dependent major elements, each requiring extensive use of new technologies. The risks involved could further increase the development costs. Proper research leading to the development of the necessary technological base and careful attention to the definition and detailed design of all shuttle elements can control costs and reduce the risk of costly overruns. Through the proper definition of the programmatic alternatives, substantial reductions may be made in both the annual funding requirements and development risk.

In consideration of the objectives of the shuttle program, and annual funding limitation and inherent developmental risk, reductions in annual funding requirements can be achieved by stretch-out of the development cycle required to achieve fully reusable elements as shown in Figure 6-1a. This approach requires a delay in FMOF and does not appear to substantially reduce the development risk due to continued parallel development of the orbiter and booster. Also, shown in Figure 6-1b, is a minimum risk stretched program in which the orbiter and booster developments are time-phased and early FMOF is achieved thru initial use of the proven S-1C Apollo hardware.

In Figure 6-2 is shown a comparison of the annual funding and total program costs as a function of the shift in the fully reusable FMOF date. Also indicated at the zero time shift is the C-4 program annual funding and total program costs. A variable increase to 10% at 5 years delay in the development costs of the stretched program was assumed. It can be seen that both alternatives offer a 30% reduction

(a) Fully Reusable

Delayed FMOF



(b) Min. Risk Fully Reusable

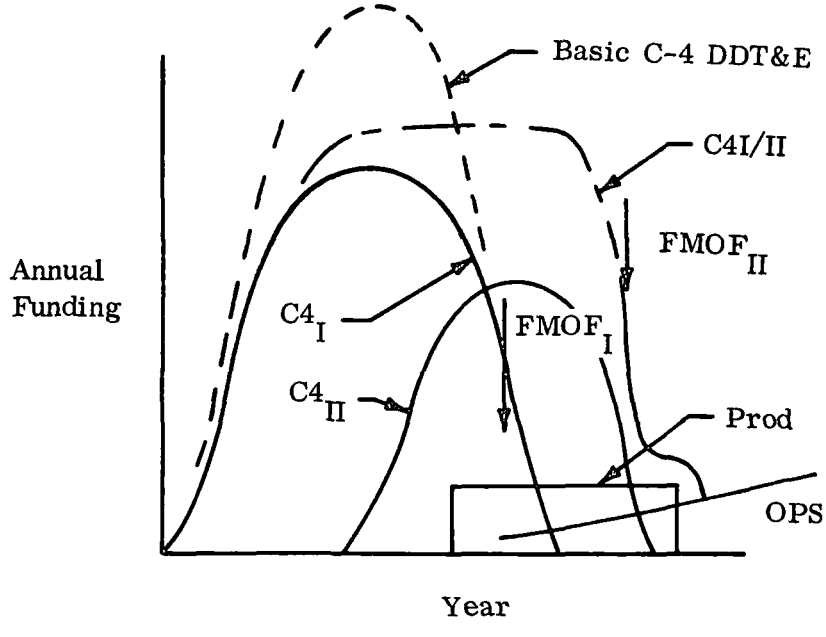


Figure 6-1. Programmatic Alternatives

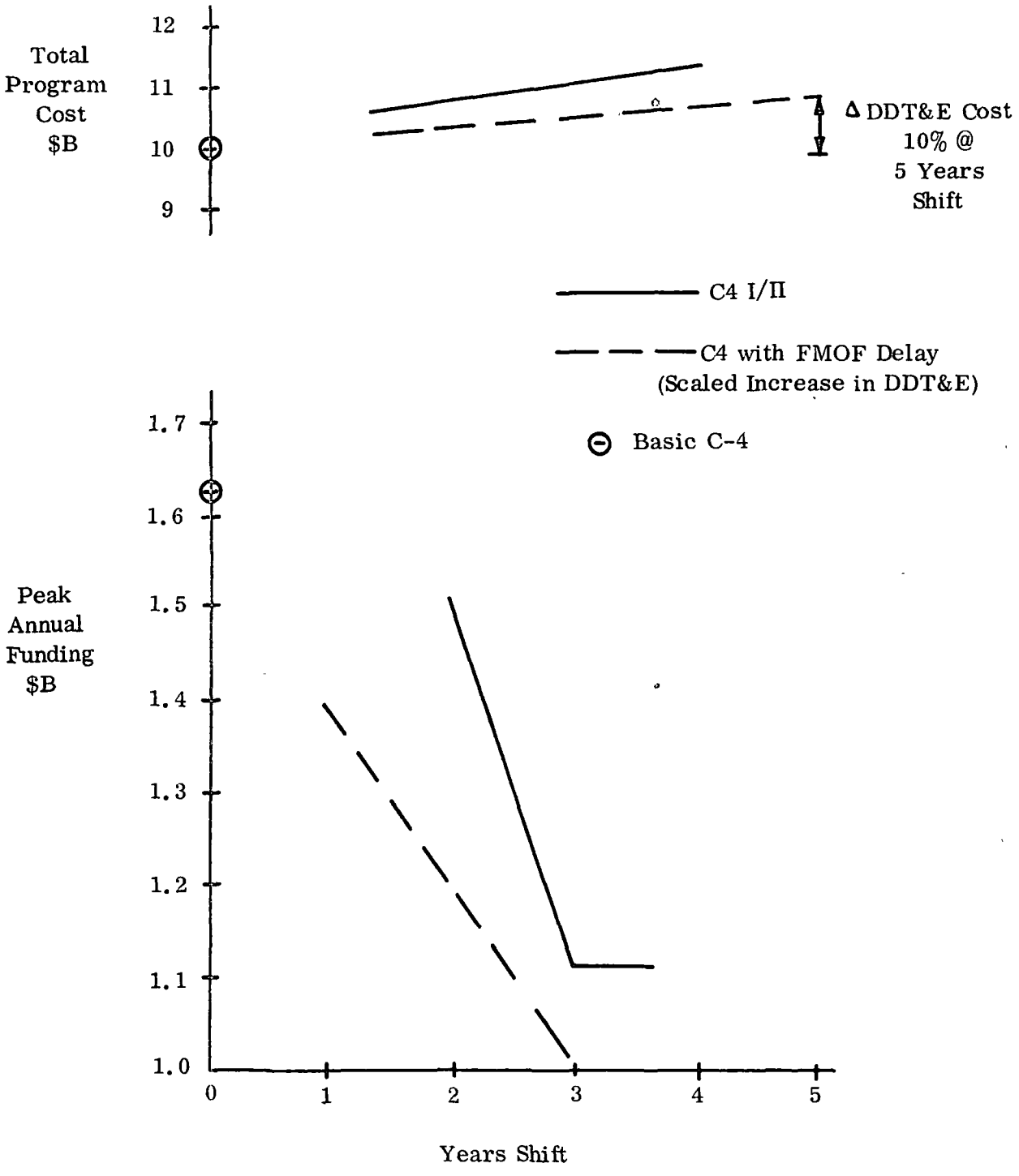


Figure 6-2. Programmatic Alternatives Cost Sensitivity to Development Options

in peak annual funding when compared to the C-4 baseline at the expense of an increase in total program of 2 to 7 percent. At three years shift, both approaches require annual budgets of about $1.0B to $1.1B.

6.1 Minimum Risk Fully Reusable Program (C4 I/II)

6.1.1 Schedule

A schedule for the minimum risk fully reusable program is shown in Figure 6-3. This programmatic alternative utilizes as Block I, a modified S-1C and new reusable orbiter. Development of the fully reusable booster (Block II) is carried along at a low rate in which the interfaces between the orbiter and fully reusable booster are defined. This will ensure a minimum scar penalty on the orbiter when finally mated to the fully reusable booster. After 4 years, the fully reusable booster development is initiated. The developed orbiter is flown on the S-1C booster at the rate of three flights per year from the initial FMOF in mid 1977. The fully reusable orbiter and booster FMOF occurs three years later in 1980. It is anticipated that the initial nine flights will be primarily developmental in nature in which all aspects of the fully reusable orbiter will be demonstrated such as TPS requirements and flight envelope, in-orbit rendezvous with Skylab and cargo/transfer, and in orbit recovery, rescue and return. Operational payloads will be carried when available. Due to the advanced state of the orbiter at this point, having solved the major technological problems during the initial Block I flight program, the annual flight rate can, as shown in Figure 6-4, increase at a more rapid rate than that anticipated for the parallel orbiter booster development of the C-4 program. This rapid increase in flight rate will allow the achievement of the full 445 flights by 1987.

6.1.2 Funding

The funding requirements by program elements for the 10 year operational program are shown in Table 6-1. The initial development of the fully reusable booster is carried at a rate of $25 million for the first four years. Also, $50 million dollars is allowed for possible orbiter modifications when converting to

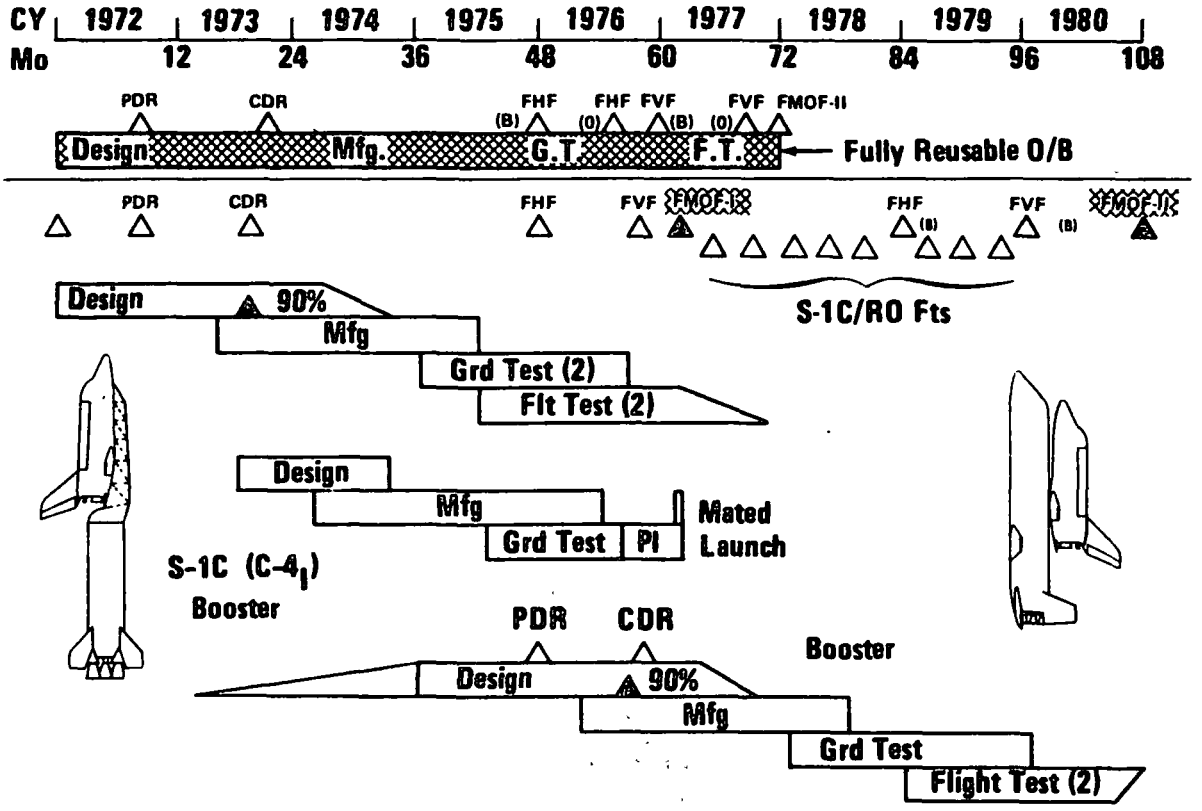


Figure 6-3. Minimum Risk Fully Reusable System, Program Schedule

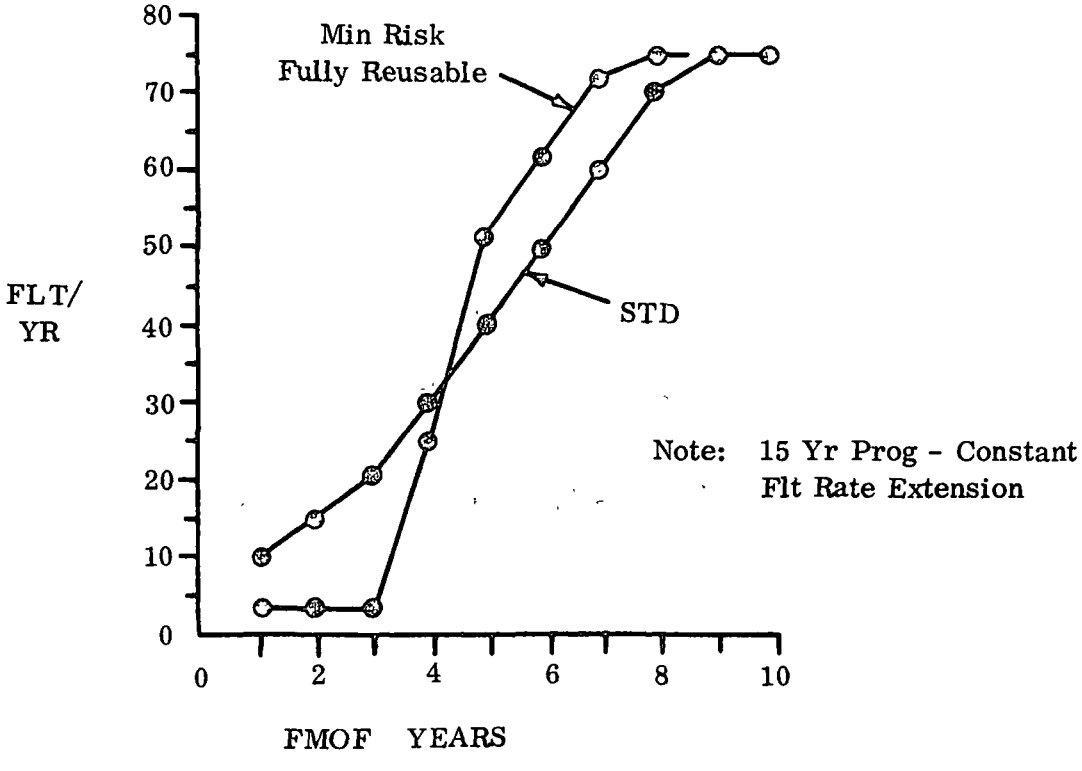


Figure 6-4. Traffic Models

TABLE 6-1a. MINIMUM RISK/FULLY REUSABLE, DDT&E COST ($C\text{-}4_I$)

$C\text{-}4_I$ DDT&E, $B	Orbiter	S-1C	Total
Orbiter D&D			2147.9
Airframe	498.5		
Engine	654.7		
Avionics	550.0		
Subsystems	444.7		
S-1C D&D			77.4
Mods		16.2	
Strongback		6.2	
S-1C Startup		29.0	
F-1 Startup		21.0	
Flight Test Instrumentation		5.0	
Test Hardware	740.8	99.6	840.4
Test Operations and Support			142.2
Facilities/GSE			200.9
Booster Sustaining			100.0
System Integration and Management			350.9
$C\text{-}4_I$ Total			3859.7

TABLE 6-1b. MINIMUM RISK/FULLY REUSABLE, DDT&E COST ($C\text{-}4_{II}$)

$C\text{-}4_{II}$ DDT&E, $B	Orbiter	Booster	Total
Reusable Vehicle			1462.8
Airframe	.050	854.6	
Engine		10.0	
Avionics		339.0	
Subsystems		209.2	
Test Hardware		1161.0	1161.0
Test Operations and Support			110.5
Facilities/GSE			189.6
System Integration and Managment			292.2
$C\text{-}4_{II}$ Total DDT&E			3216.3
$C\text{-}4_{I}$ Total DDT&E			3859.7
$C\text{-}4_{I/II}$ Total DDT&E			7076.0
C-4 Total DDT&E			6901.0

TABLE 6-1c. MINIMUM RISK/FULLY REUSABLE, PROGRAM COST

$C\text{-}4_{I/II}$ Total Program Cost, $B	C-4 Orbiter	S-IC	C-4 Booster	Total
DDT&E				7076.0
Vehicle	2147.9	77.4	1462.8	
Test Hardware	740.8	99.6	1161.0	
Test Operations and Support	252.7			
Facilities/GSE	390.5			
Booster Sustaining	100.0			
System Integration and Management	643.1			
Production				2185.1
Flight Articles	659.0	324.4	1031.0	
Test Hardware Conversion	30.0	—	37.0	
System Integration and Management	103.7			
Operations				1545.4
Operations/Support and Materials	1471.8			
System Integration and Management	73.6			
Total Program - 445 Flights				10806.5

the fully reusable orbiter. The orbiter is basically developed from the C-4 configuration. An increase in $30 million in avionic development costs has been used for the orbiter since it is required to operate on the S-1C. A detailed breakdown of the S-1C costs are shown in Table 6-2. A total DDT&E cost of $199.3M is used for the minimum risk fully reusable S-1C. This includes $29M in start-up for the basic S-1C and $21M in start-up for the F-1 engines. The test program cost $121.9M including two test articles, static and dynamic tests, engine support, base maintenance and spares. The unit cost of all eleven basic S-1C vehicles used in Block I is listed in Table 6-2. The first three vehicles follow an 83% learning curve and the remaining eight follow an 86% learning curve. They are derived for a production rate of three per year. All F-1 engines are costed at an average cost of $1.8M per engine. The test program costs shown in Table 6-3 are based on two vertical suborbital tests prior to Block I FMOF. This shortened test program, achievable with the proven S-1C hardware, allows for the mid-1977 FMOF.

The operational costs are shown in Table 6-4. The costs during Block II operations are essentially those of the C-4 program; however, since the Block II program is seven years rather than 10, the facility and GSE maintenance requirements are somewhat reduced.

The annual funding requirements are shown in Figure 6-5. A comparison of annual funding with the C-4 program shows a 32% reduction in peak annual funding from $1.65 billion for the C-4 program to about $1.1 for the C4 I/II program. In Figure 6-6 is shown the cumulative program costs without discounting for the basic 10 year program and a 15 year program in which four orbiters and four boosters have been added and 75 additional flights are added per year from 1988 to 1992. A comparison of the C-4 I/II program costs with the C-4 program is shown in Figure 6-7 for no discounting and 5% and 10% discounting; similarly in Figure 6-8 for a 15-year program. Although the total program costs of the C-4 I/II program are increased over the C-4, the low initial funding results in a lower discounted costs for discount rates greater than 4.5% as shown in Figure 6-9.

TABLE 6-2a. MINIMUM RISK PROGRAM S-1C
DDT & E COST SUMMARY

DDT&E		
DESIGN & DEVELOPMENT		$ 77.4
MANUFACTURING FACILITIES		3.3
TEST PROGRAM - 2 VEHICLES		
BASIC S-1C	$ 65.43	
MODIFICATIONS	11.60	
STRONGBACK	3.90	
SUBTOTAL	$ 80.93	80.3
ENGINES		18.0
TEST OPERATIONS		
STATIC TEST	9.80	
DYNAMIC TEST	1.30	
ENGINE SUPPORT	6.00	
BASE MAINTENANCE	1.90	
SPARES	2.0	
SUBTOTAL OPERATIONS	$ 21.00	21.0
TOTAL DDT&E		$200.6

TABLE 6-2b. MINIMUM RISK PROGRAM
S-1C PRODUCTIONS COSTS

PRODUCTION (9 UNITS)		324.4
BASIC S-1C	188.9	
MODS	38.6	
STRONGBACK	9.5	
ENGINE	81.0	
SPARES	6.4	

The cost per flight summary for the minimum risk fully reusable program is shown in Table 6-5 for both Block I and II. The cost per flight for the first nine flights is $57.5M and $31.M for the remaining 436 flights.

6.1.3 Minimum Risk Approach

The mutual coupling of the orbiter and booster in parallel development results is high risk since both orbiter and booster depend on rather substantial advances in the engine, materials and aerothermal design state-of-the-art. Decoupling the orbiter and booster development cycles so as to provide for tandem rather than parallel schedules will greatly reduce the development risk. An example of the reduction is shown in Figure 6-10, where the payload sensitivity is shown for configurations A-3, B-2I, C-4 and C-4 I/II. The payload sensitivity is defined as that payload which must be removed to compensate for an inert weight increase while maintaining constant performance. All concepts except the minimum risk approach show about a 2500 pound payload reduction for each percent of inert weight average. In the case of the minimum risk approach, the S-1C has adequate throw weight capability to handle orbiter gross weight overages

TABLE 6-3. MINIMUM RISK FULLY REUSABLE PROGRAM TEST OPERATIONS AND SUPPORT

	$C\text{-}4_I$		$C\text{-}4_{II}$	
	S-1C	Orbiter	Orbiter	Reusable Booster
$C\text{-}4_I$				
Ground Test	1.7	20		
Horizontal Flight Test	-	21.2		
Vertical Flight Test	14.8	15.3		
Test OPS and Support	12.6	46.3		
Static Test (Strongback)	9.8	-		
Propellants	.5			
$C\text{-}4_{II}$				
Ground Test OPS				27.5
Horizontal Flight Test				17.4
Vertical Flight Test				15.0
Base Support			47.6	
Propellants			3.0	

TABLE 6-4. MINIMUM RISK FULLY REUSABLE PROGRAM FACILITIES AND GSE - 445 FLIGHTS

	$C\text{-}4_I$		$C\text{-}4_{II}$	
	S-1C	Orbiter	Combined	Booster
Manufacturing		16.2		24.9
Launch and Recovery		24.4	28.7	
Maintenance and Refurbishment Facility				5.0
Test Facilities/GSE		12.0		18.2
Test Operations Facilities/GSE	108.6	2.7	23.4	71.4
S1C Test Facility	1.0			
Additional Production and Oper. Fac/GSE		2.7	18.2	10.0
Trainers & Simulators		1.0	10.0	
Special Test Equipment	3.0	23.0	8.0	

TABLE 6-5. MINIMUM RISK FULLY REUSABLE PROGRAM OPERATIONS AND EXPENDABLE COST PER FLIGHT - 445 FLIGHTS

	$C\text{-}4_I$ / $C\text{-}4_{II}$
Expendable Hardware	36.0 / -
Orbiter Refurbishment Material	.60 / .60
Booster Refurbishment Material	- / .79
FAC/GSE Refurbishment Material	3.33 / .32
Propellants	.27 / .47
Operations And Support	14.44 / .78
System Integration/Mgt	2.75/ .14
Cost/Flt	57.3/3.10

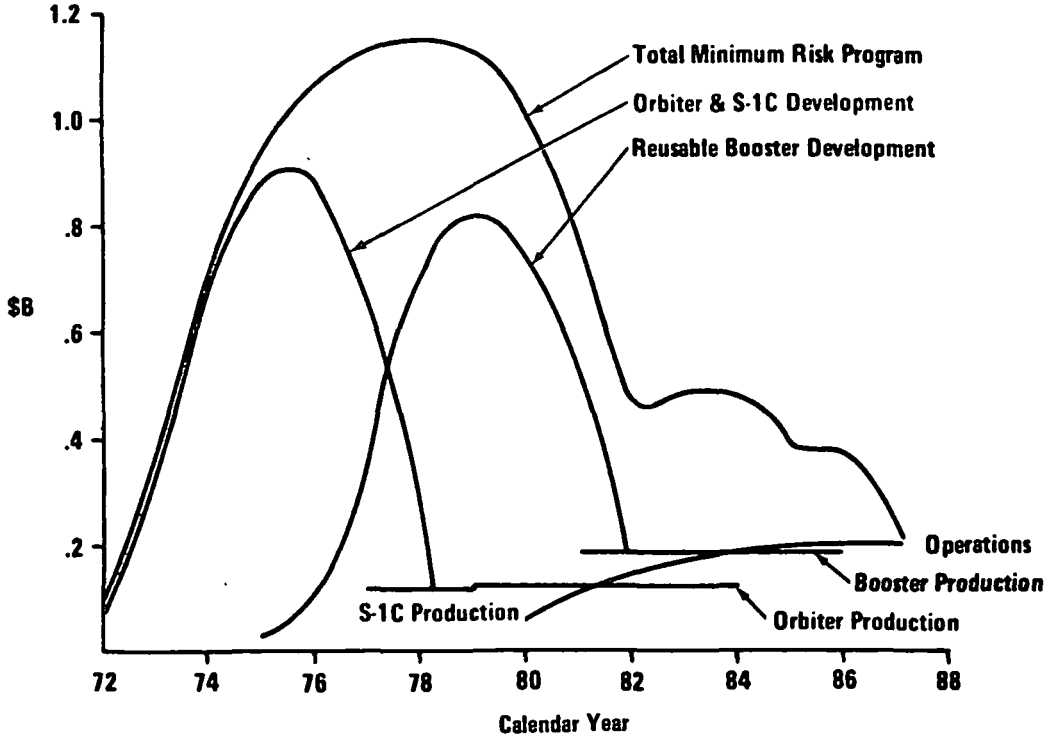


Figure 6-5. Minimum Risk/FR Annual Costs

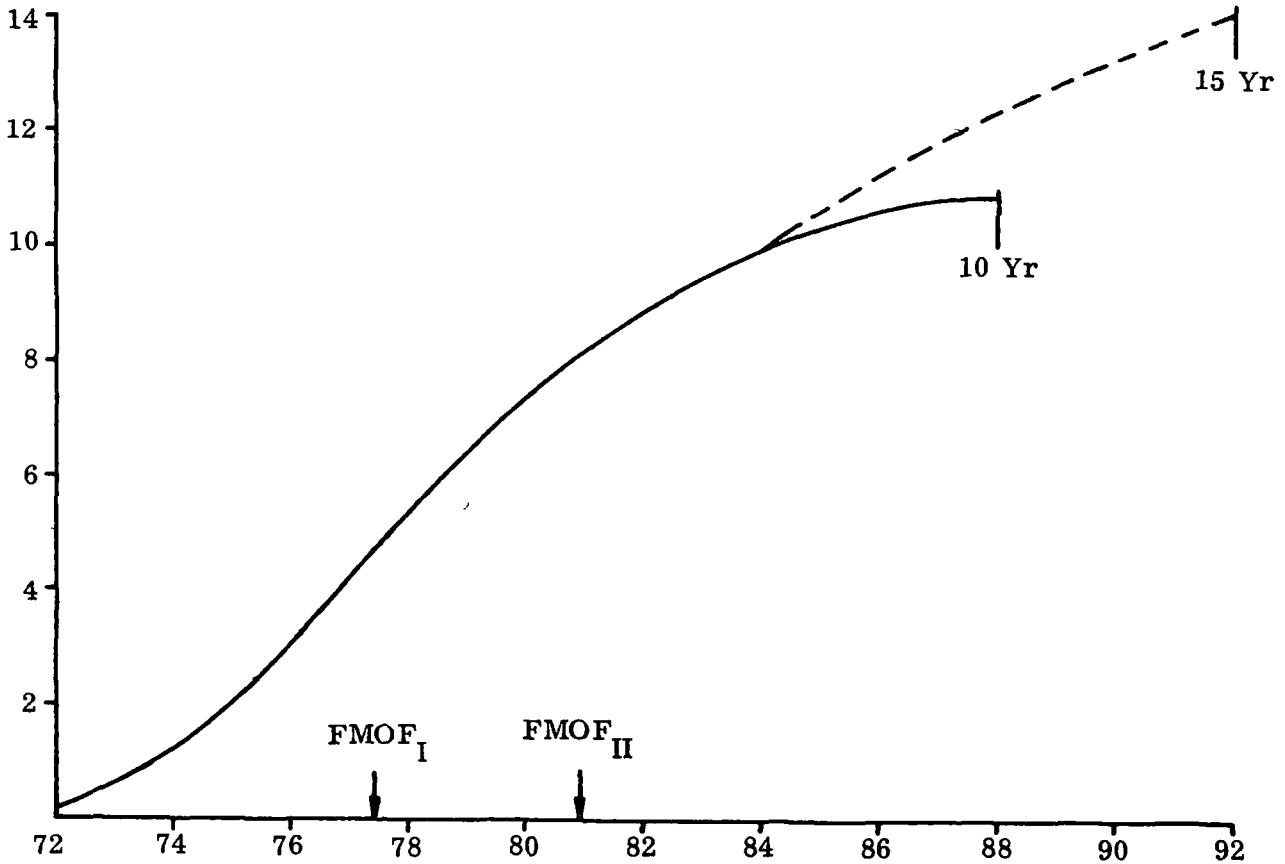


Figure 6-6. Cumulative Cost - No Discounting, C-4$_{I/II}$

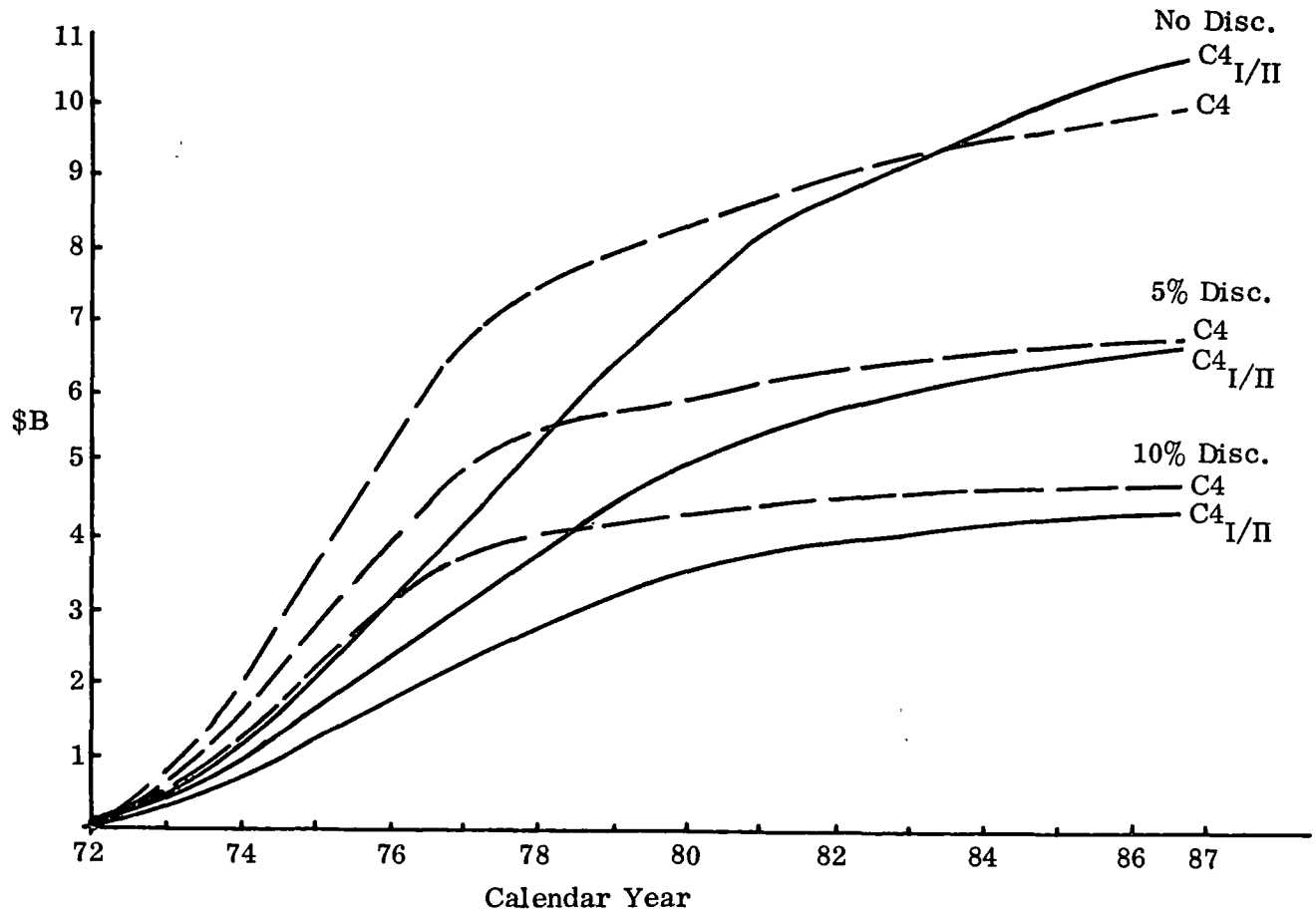


Figure 6-7. Minimum Risk Fully Reusable Cumulative Costs - 10 Year Program

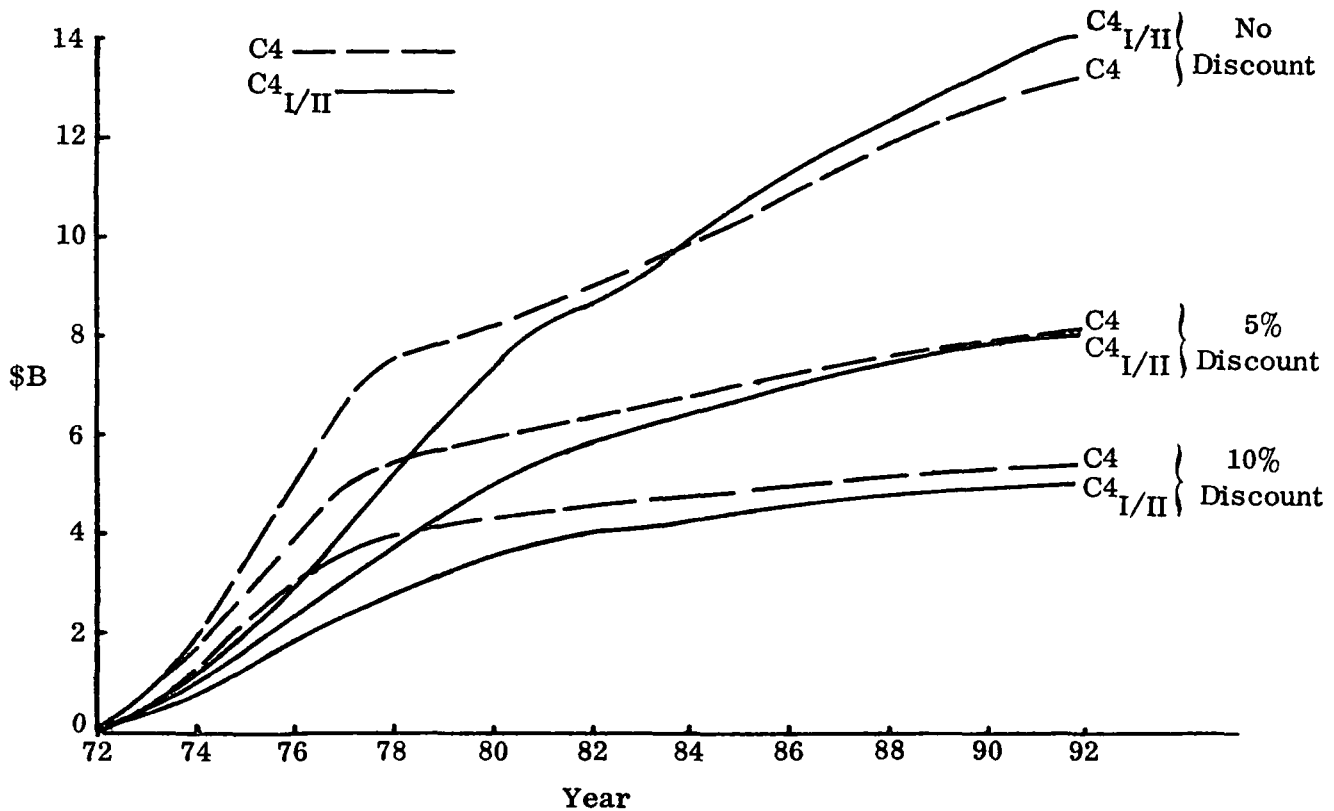


Figure 6-8. Minimum Risk Fully Reusable and C-4 Cumulative Costs - 15 Year Program

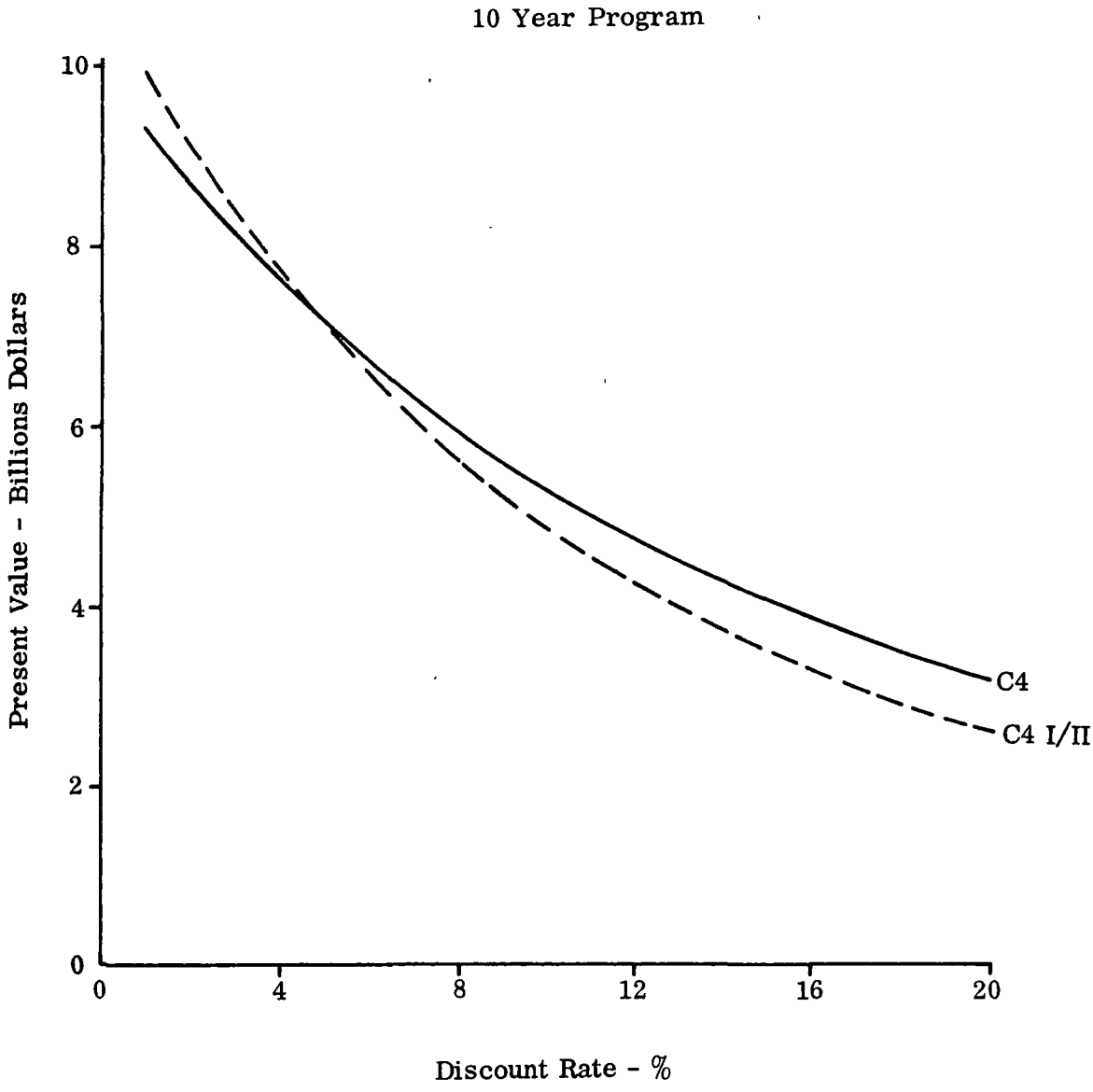


Figure 6-9. Effect of Varying Discount Rate

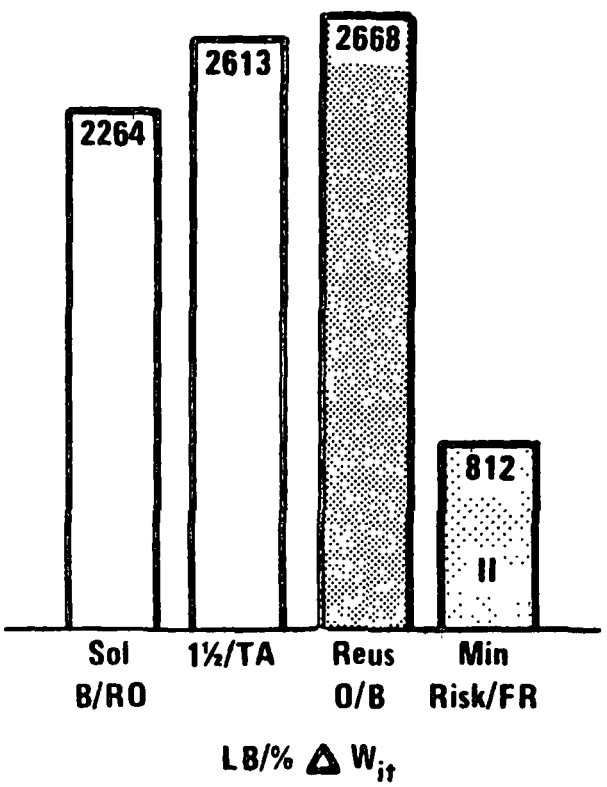


Figure 6-10. Concept Comparison, Payload Sensitivity

of up to 50 thousand pounds. With the orbiter fully defined, and operating, the fully reusable booster development can proceed uncoupled from the orbiter resulting in a payload sensitivity for Block II of only 812 pounds per percent of inert weight average. The losses in payload noted above could result in increased cost per pound in orbit or very costly research and development efforts to increase the payload to the initial design values.

6.1.4 Summary

The major cost elements of the minimum risk fully reusable program are summarized in Table 6-6.

6.1.5 NASA Cost Data Forms A & D

The NASA cost data forms A and D in accordance with the requirements of DRD MF-003M are included as Tables 6-7 to 6-12.

TABLE 6-6. MINIMUM RISK FULLY REUSABLE TOTAL COST SUMMARY

DDT & E	~ $B		7.076
Total Program	~ $B	10 Yr	10.806
		15 Yr*	12.600
Cost/Flight (OP & EXP.)	~ $M	$C\text{-}4_I/C\text{-}4_{II}$	57.5/3.1
Peak Annual Funding	~ $B		1.1
Payload Sensitivity	~ $LB/\%W_I$		812
FMOF	~ Year	$C\text{-}4_I/C\text{-}4_{II}$	77/80

*No Vehicle Life Limit

TABLE 6-7.

COST ESTIMATE DATA FORM A

Date 12-11-70

X Non-Recurring (DDT&E)

_____ Recurring (Production)

_____ Recurring (Operations)

Page 1 of 1

VEHICLE CONFIGURATION C4I/II

NO. OF FLTS. 445

WBS Identification No.	WBS Item Name	WBS Item Cost	Number of Units
	Orbiter	2630.3	3
	Booster	2815.8	$2\ B_I + 2\ B_{II}$
	Main Engine	654.7	-
	Flight Test	331.9	-
	Program Management	643.3	-

TABLE 6-8

COST ESTIMATE DATA FORM D — Date 12-11-70

X Non-Recurring (DDT&E) — Page 1 of 1

____ Recurring (Production)

____ Recurring (Operations)

VEHICLE CONFIGURATION C4 I/II — NO. OF FLTS. 445

Project WBS Items	FY 72	FY 73	FY 74	FY 75	FY 76	FY 77	FY 78	FY 79	FY 80	FY 81	FY 82
Orbiter	9.2	177.0	464.7	664.2	664.2	464.7	177.0	9.3			
Booster	11.8	25.0	25.0	25.0	62.0	210.0	402.0	652.0	670.0	533.0	200.0
Main Engine	2.7	43.0	116.0	166.0	166.0	116.0	43.0	2.0			
Flight Test	.5	9.4	30.0	56.0	74.0	85.0	66.0	11.0			
Program Management	33.7	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0	64.0	33.6

TABLE 6-9.

COST ESTIMATE DATA FORM A

Date 12-11-70

_____ Non-Recurring (DDT&E)

Page 1 of 1

_X_ Recurring (Production)

_____ Recurring (Operations)

VEHICLE CONFIGURATION C4I/II

NO. OF FLTS. 445

WBS Identification No.	WBS Item Name	WBS Item Cost	Number of Units
	Orbiter	989.0	2
	Booster	926.8	$9\ B_I + 3\ B_{II}$
	Main Engine	165.6	4 orb. $+ 36\ B_{II}$
	Flight Test	*	-
	Program Management	104.0	-

*Included In Orbiter & Booster Cost

TABLE 6-10

COST ESTIMATE DATA FORM D

Date 12-11-70

Page 1 of 1

_____ Non-Recurring (DDT&E)

_X_ Recurring (Production)

_____ Recurring (Operations)

VEHICLE CONFIGURATION C4 I/II

NO. OF FLTS. 445

Project WBS Items	FY 77	FY 78	FY 79	FY 80	FY 81	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87
Orbiter	58.0	108.0	173.2	169.9	103.6	106.3	106.0	106.0	58.0		
Booster					84.0	166.0	157.0	148.0	149.0	149.0	73.8
Main Engine			13.4	27.4	28.0	28.0	28.0	27.4	13.4		
Flight Test *											
Program Management	5.2	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	5.2

*Included In Orbiter & Booster Cost

TABLE 6-11.

COST ESTIMATE DATA FORM A

Date 12-11-70

_____ Non-Recurring (DDT&E)

Page 1 of 1

_____ Recurring (Production)

__X__ Recurring (Operations)

VEHICLE CONFIGURATION C4I/II

NO. OF FLTS. 445

WBS Identification No.	WBS Item Name	WBS Item Cost	Number of Units
	Operations	1471.8	
	Program Management	73.6	

TABLE 6-12

COST ESTIMATE DATA FORM D

Date 12-11-70

_____ Non-Recurring (DDT&E)

Page 1 of 1

_____ Recurring (Production)

X Recurring (Operations)

VEHICLE CONFIGURATION C4 I/II

NO. OF FLTS. 445

Project WBS Items	FY 78	FY 79	FY 80	FY 81	FY 82	FY 83	FY 84	FY 85	FY 86	FY 87	FY 88
Operations	35.9	57.7	59.7	89.7	139.7	169.7	189.7	204.7	209.7	209.7	105.6
Program Management	1.8	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	2.5

Appendix P

ORBITER/BOOSTER HEATSINK-RADIATIVE TPS

P.1 INTRODUCTION

A cost study was performed to obtain a cost for the C-2 Booster TPS from a representative design. Those costs were applied as unit costs to obtain the cost of total Orbiter/ Booster systems. Total systems were defined which had various trajectories and utilized different amounts of primary structure as a heat sink to reduce the amount of reradiative heat shields required on the Booster.

The objective of the study was to determine what percent of surface area should be used as a heat sink to produce the lowest overall system cost. A secondary objective was to identify all the elements affecting the costs of the TPS so that realistic costs could be developed and iterations in the system could be evaluated.

The cost study was performed in five major steps:

- Determine unit cost of each type of heat shield. The flow diagram, Figure P-1 illustrates a plan for developing the TPS unit costs
- Determine total cost of TPS on vehicles designed for different percent of heat sink area, staging velocities, thermal heating uncertainty factor for turbulence and various propellant tank initial temperature
- Determine unit and total cost of booster system without the TPS
- Determine total cost of Orbiter system
- Combine TPS cost with Booster and Orbiter system costs for all Booster/Orbiter system configurations.

All system total costs include three categories: RDT&E, investment and operations. The content of each of these categories is defined under the following section on determination of Unit TPS costs.

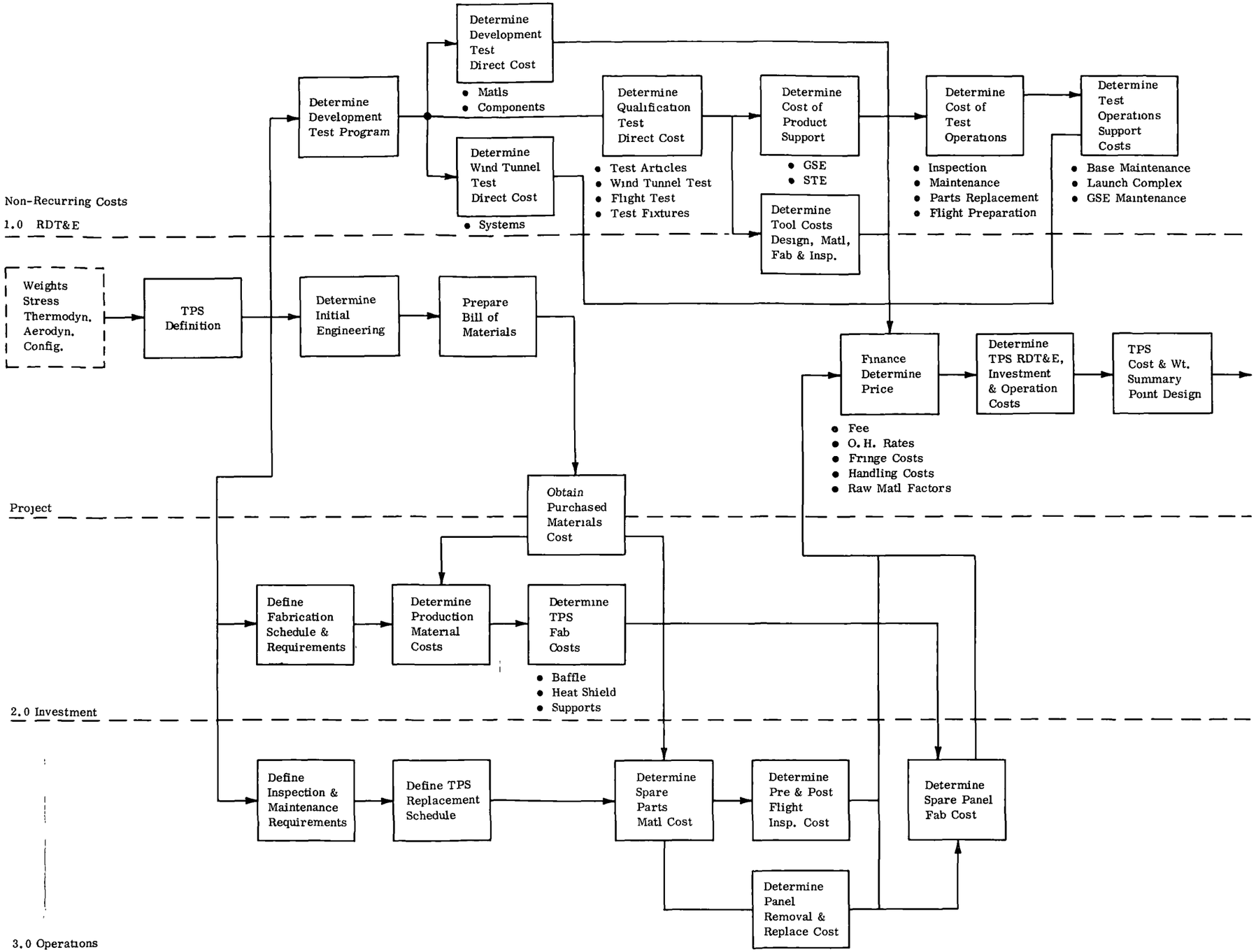


Figure P-1. Flow Diagram-TPS Unit Cost Determination

P.1.1 Unit TPS Cost Determination

The first step was to determine the unit costs of a detail design to obtain unit costs of heat shields made of the materials selected for the C-2 Booster. The costs were divided into three categories: RDT&E (non-recurring costs), Investment (recurring costs) and operations (or costs dependent upon time and number of flights).

P.1.2 Ground Rules and Assumptions

The Booster selected for determination the TPS unit costs is identified as configuration C-2i (Model 164-10006) as shown in Figure P-2. The following ground rules and assumptions were made to constrain the booster definition for this phase of the study:

- The Booster would have a staging velocity of 10,700 fps
- Maximum load factor of 5 g would be maintained by varying the angle of attack. A maximum angle of attack of 60° would be used
- Five Boosters would be manufactured at the rate of one every two years starting in July 1976
- The Booster will be designed for a useful life of 100 flights
- The total number of flights that will be flown is 445, before the end of 1987
- Staging altitude 238,000 ft
- Materials used for heat shields will be:

Columbium 103	1600 - 2300°F
René 41	1000 - 1600°F
Titanium 62-42	Below 1000°F

- All costs will have Finance escalation factors to cover overhead, fringe benefit costs, and profit so that the estimate will be for total contract price

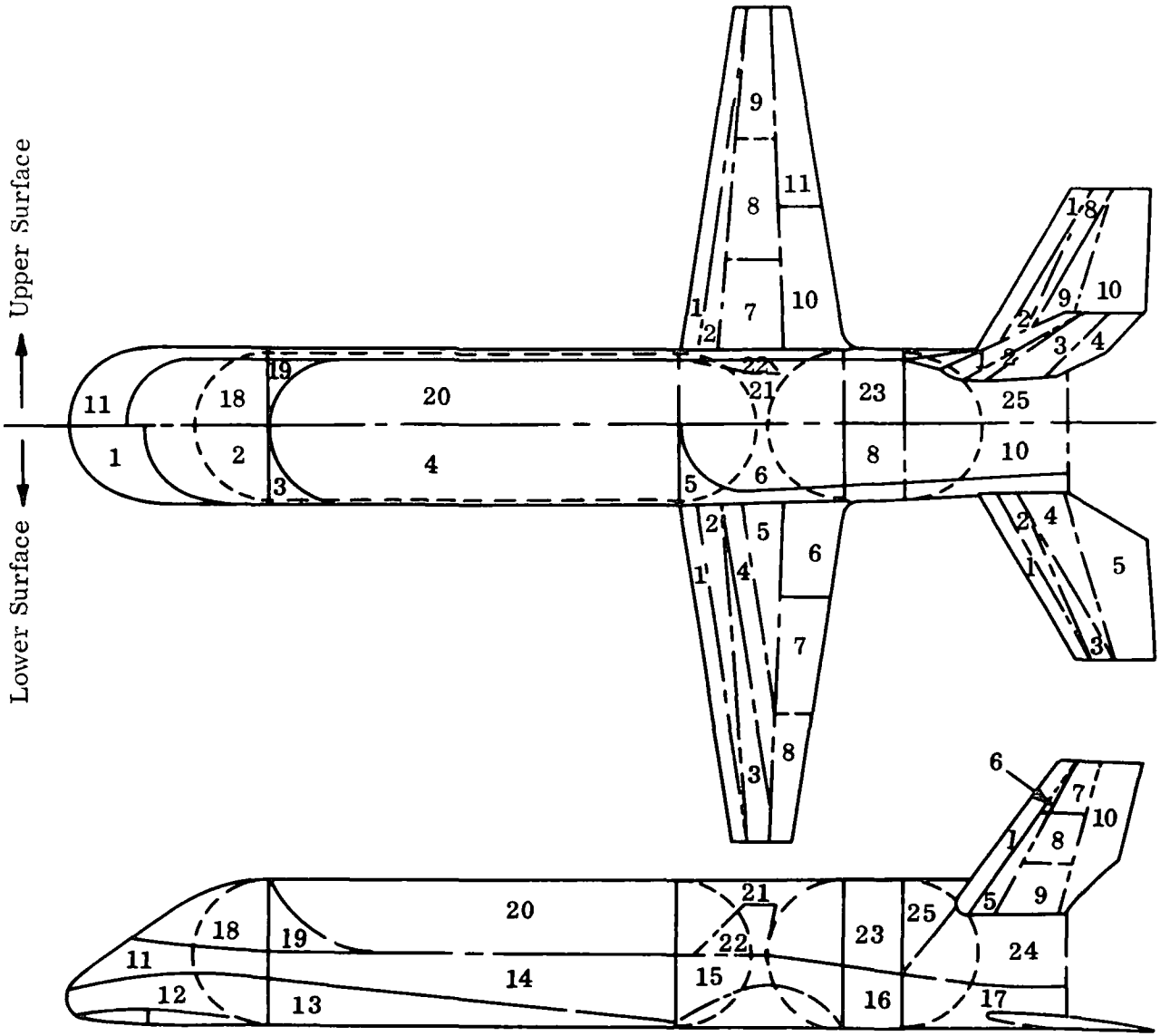


Figure P-2. Model for Heat Sink Study, Configuration C-2i

P.1.3 RDT&E Cost Determination

The non-recurring costs were divided into eight categories as follows:

- Material development
- Panel development
- Aerothermodynamics
- Panel Qualifications
- System qualification
- Flight tests
- Tool design, planning, fabrication, quality control, and material design

The first six items, material development, panel development, aerothermodynamics, panel qualification, system qualification, and flight testing were estimated to satisfy the tests outlined below. The test schedule was defined as shown in Figure P-3.

P.2 C-2I/F BOOSTER TPS STUDY TEST PROGRAM OUTLINE

P.2.1 Material Development Tests

- Determine percent creep after exposure to stresses and temperatures that will produce 1/2, 1.0, and 1-1/2% creep for 100, seven minute cycles and a range of temperatures as follows:

Titanium 6 Al-2Sn-4 Zn-2 Mo	RT to 1000°F
René 41	1000°F to 1600°F
Columbium 103	1600°F to 2300°F

- Determine strength of materials following the above tests.

P.2.2 Panel Development Tests

Development tests consist of tests to determine the performance of detail heat shield, thermal baffles, insulation and combinations of various TPS components when exposed to environments encountered during boost and reentry. The following

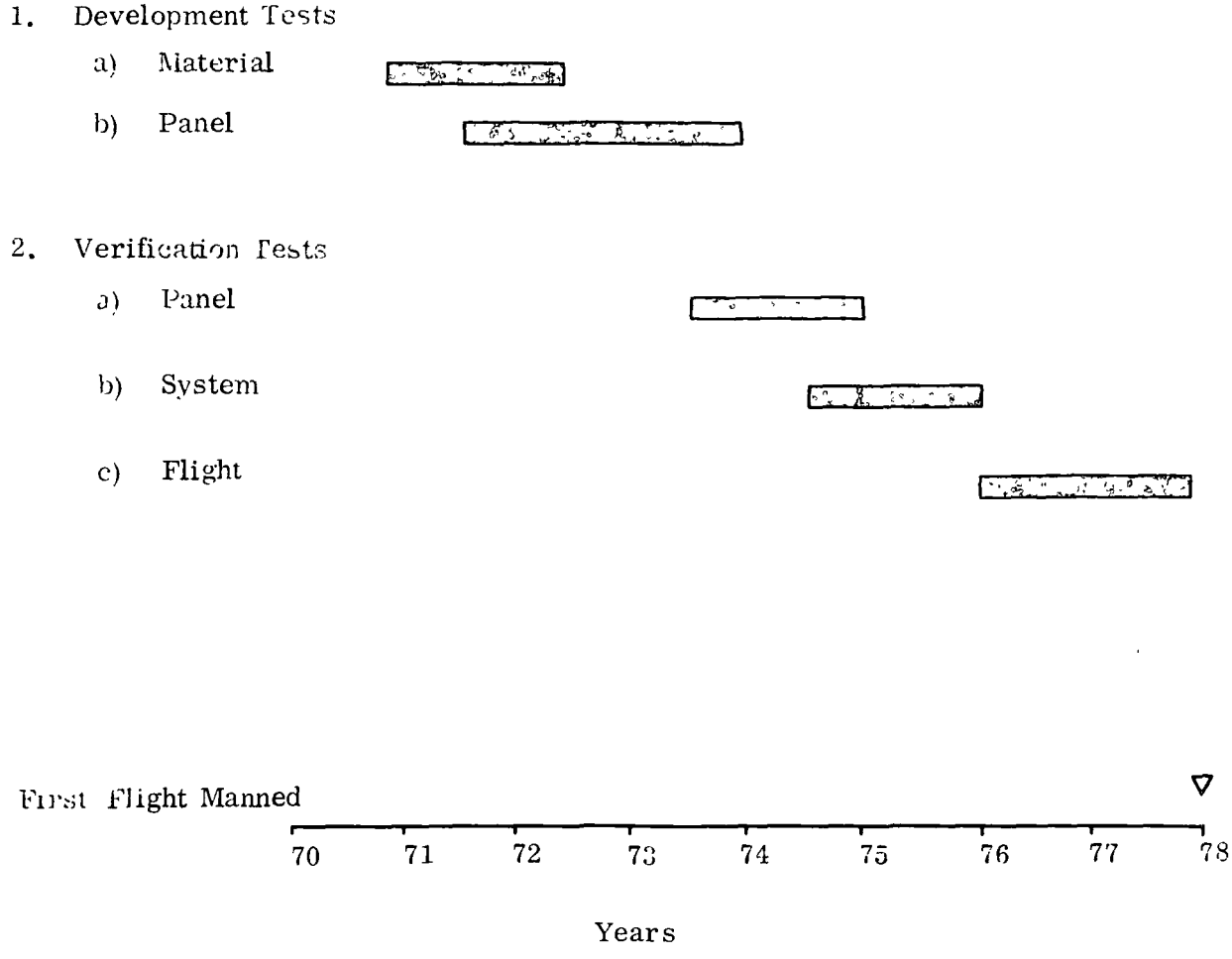


Figure P-3. C-2 Booster TPS Study Test Program

development tests are identified as necessary to obtain data and verify that the TPS design technology is adequately advanced for the C-2-I/F booster.

The following tests will be required on panels made of Titanium 6 Al-2-Sn-4 Zn - 2 Mo, René 41 and Columbium 103 for temperature ranges noted in item a above.

P. 2. 2. 1 Joint Seal Tests

This test program will evaluate a minimum of three joint designs, fabricate a test joint and determine its capability to withstand the booster flight environment and determine the joint leakage at different temperatures and pressures. This test will be performed on joints connecting two small panels about 10 x 20 inches simulating a joint between two panels. Four typical joints will be simulated and tested.

P. 2. 2. 2 Thermal Baffle Test

Three different thermal baffles will be selected from all suitable concepts and two tests will be run on each baffle design to determine the baffle thermal characteristic and develop thermal data to verify the calculated baffle operating characteristic. At least four temperature points will be investigated for each baffle and baffle life data will be predicted up to 100 flights. TPS backside temperatures will be measured.

P. 2. 2. 3 Insulation Tests

Insulation suitable for the booster applications will be tabulated and three different designs will be tested to verify their thermal insulating characteristics and establish rates of degradation of the insulation characteristics up to 100 flights. Data will be used to verify calculated data and to establish a satisfactory design for the booster.

P. 2. 2. 4 Panel Acoustic Tests

The TPS with heat shield baffles and insulation will be subjected to 155 db overall in a simulated flight condition including reentry and the design capability to

withstand the acoustic levels and strains developed during the test, will be determined. Three configurations will be checked for the booster flight environment which shall include the temperature and pressure encountered and at least two additional environments, one more extreme and one not as extreme. The support structure and understructure shall be simulated and the capability of the designs shall be determined by increasing the environments until failure occurs.

P. 2. 2. 5 Life Tests

Three TPS test panels shall be cycled until failure or 100 cycles, whichever occurs first. Each test panel shall be cycled through a simulated flight from boost to landing and preparation for boost. Temperatures and pressures used shall be as near to actual flight conditions as can be simulated on the ground using state-of-the-art test equipment. Failure modes shall be identified and means to determine the need to replace the panel shall be established.

Simulated flight tests will be performed in wind tunnels on a scale model of the booster with and without an orbiter installed. The following tests are required:

P. 2. 2. 6 Interference Heating

A scale model will be tested to determine the temperature and pressure distribution over the entire booster when the orbiter is being transported. The data obtained will be used to design the TPS. Sixty hours of wind tunnel testing is required.

P. 2. 2. 7 Temperature and Pressure Distribution

Temperature and pressure distribution and values will be determined following ejection of the simulated orbiter during reentry into the atmosphere. This test will verify the analytical methods that were used to determine the temperature and pressure distribution for the TPS design. One hundred sixty hours of wind tunnel testing is required.

P. 2. 2. 8 Surface Roughness

An evaluation of the effect of roughness of the TPS panel on its capability to withstand the range of temperatures for which it is designed, and the effect of roughness on the TPS panel life will be made. It is estimated that 80 hours of wind tunnel testing is required.

P. 2. 3 Panel Verification (Qualification)

Nine different test panels, three for each material, will be exposed to its life cycles at the maximum temperature for which it was designed as follows:

Panel Material	Life Cycles	Max Temp
Columbium 103	10	2300°F
René 41	50	1600°F
Titanium 6 Al-2 Sn - 4 Zn - 2 Mo	100	1000°F

P. 2. 4 System Verification (Qualification)

Two tests will be run on test models, one to simulate boost conditions with the orbiter installed to determine that temperature and pressure distributions used in design are correct, and one condition simulating reentry.

P. 2. 4. 1 Launch Condition

A model of the combined booster-orbiter will be checked in a wind tunnel under simulated launch conditions to determine the temperature and pressure distributions. Eighty hours of wind tunnel testing is required.

P. 2. 4. 2 Reentry Condition

A scale model of the booster will be tested in a wind tunnel under simulated reentry conditions. The temperature and pressure distribution will be determined to check the design. Eighty hours of wind tunnel testing is required.

P. 2. 5 Flight Tests

On the first three unmanned flights the temperature and pressures will be recorded for all critical heating areas. A minimum of 100 points will be measured

on each major structural component, (body, wing and control systems). A thorough inspection and evaluation will follow each flight to determine the TPS adequacy and estimate the required replacement parts.

The tool design, planning, fabrication materials and QC costs were estimated by manufacturing to support the investment costs and included in the RDT&E category because they are non-recurring costs. A description of the approach to obtaining investment (or fabrication) costs is in the following section. The design costs were obtained by estimating the design engineering and drafting time required to design and produce drawings of the TPS heat shield only and does not include special problems, staff, support or test support. The RDT&E costs were then distributed according to the estimated requirements for Columbium 103, René 41 and Titanium 6242. Since RDT&E costs are not dependent entirely upon size or weight but more upon development of new materials or processes the unit cost of RDT&E for any one vehicle can not be used to determine the actual costs of other vehicles. A better assessment of the TPS RDT&E costs for boosters with varying features were determined by establishing a basic cost and cost of development of each heat shield having different materials. RDT&E costs for the Thermal Protection System are shown in Figure P-4.

P.2.6 Investment Costs (recurring)

Estimation of the TPS investment (or recurring) costs were made as follows:

- Major assemblies of the Booster were divided into areas and identified by number (25 areas on the body, 15 areas on the wing, 9 areas on the horizontal tail, and 10 areas on the vertical tails) and according to heat shield temperature
- Define the TPS for each identified area and determine the unit weight and material required to manufacture it
- Obtain cost of the raw materials by preparing a material list and obtaining cost for each item by quantity required to produce parts

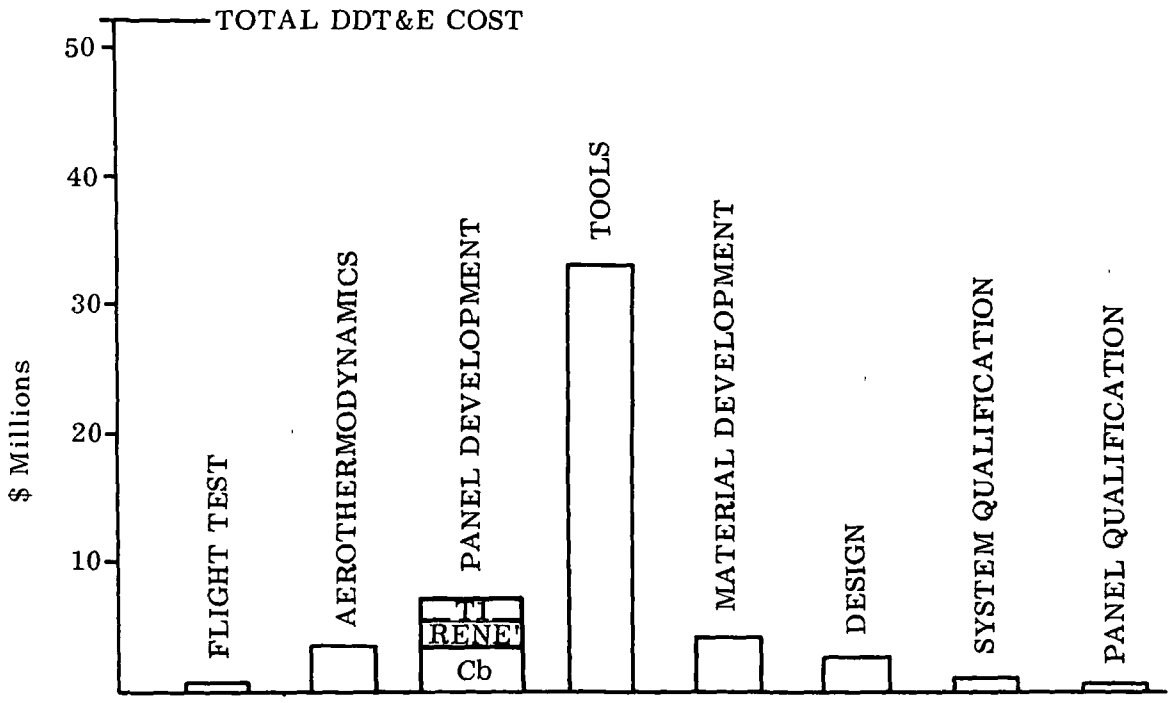


Figure P-4. Thermal Protection System DDT&E Costs

- Obtain cost of panel fabrication by obtaining base factory hours, and applying factor required to determine cost
- Estimate cost of baffle and its installation
- Obtain estimate of cost of cooling the Columbium panels
- Estimate cost of tool sustaining and Quality Control
- Combine all estimated costs for each panel for the identified elements of the major assemblies to determine the cost per square foot of the panel designed for that element
- Determine investment cost by multiplying the cost per square foot for each element by the area of the element.

The cost per square foot to fabricate the panels is plotted against the unit weight of the panels to obtain the cost of panels of varying unit weights and materials. The results of such an analysis are shown in Figure P-5.

P.2.6.1 Operations Cost Determination

The third estimate made to obtain total cost of the TPS system is for the cost of operations. This estimate is made for 100 flights on one booster to obtain the average cost of one flight. The following steps were made to obtain the cost of operations:

- Establish a replacement schedule by material for the TPS heat shields for 100 flights
- Estimate the cost of inspection of the TPS on the Booster before and after each flight
- Estimate the cost of the spare panels by material for replacing rejected panels for 100 flights
- Estimate cost of removal and replacement of a spare panel

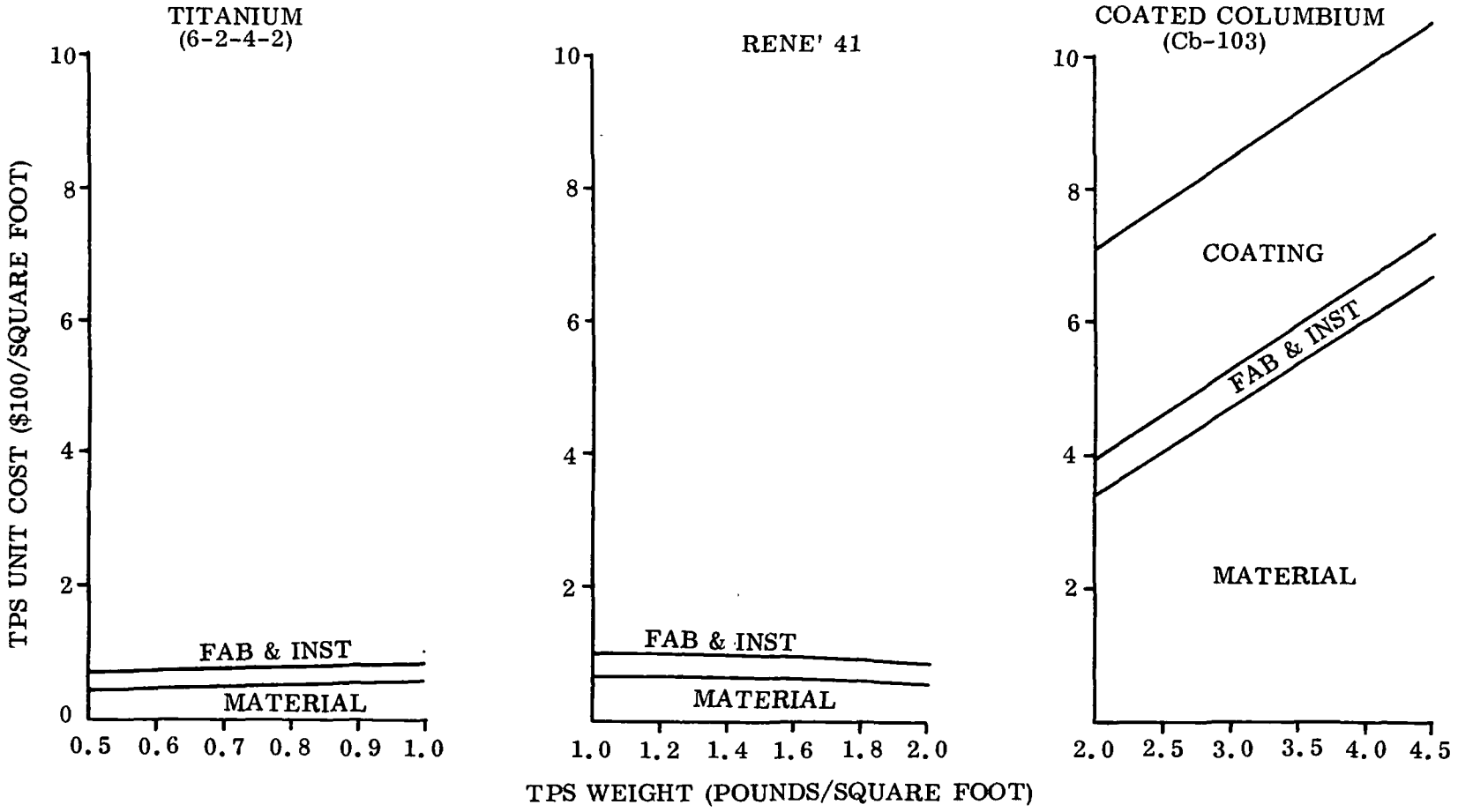


Figure P-5. Thermal Protection System Investment Costs

- Calculate the cost of inspection, removal and replacement of rejected panels for 100 flights. This includes the cost of material and fabrication of panels replaced in accordance with the replacement schedule, Figure P-6.
- Estimate cost of removal and replacement of baffles for 100 flights
- Determine cost of operations for 100 flights by summing all of the estimates made for each material used
- Determine cost per square foot for 100 flights for each material by dividing the cost of panels of identical material by the area covered by that material.

The unit cost determined provides an operations cost for any vehicle using heat shields made of Columbium, René 41 or Titanium and making 100 flights.

Estimating of the RDT&E costs, investment cost, and operation cost for a Booster with 100 percent reradiative heat shield provides a base for estimating the costs of any vehicle if the area, material and weight per square foot are known.

P.2.6.2 TPS Cost Determination for Heat Sink Study Boosters

The second major step in the study is to determine the TPS cost for the 31 Boosters having 0, 20, 40 and 60 percent heat sink areas and staging velocities of 7700, 8700, 4940 and 10,700 feet per second.

The following steps were taken to estimate each Booster TPS cost:

- The weight per square foot, material and areas covered were determined for each Booster studied
- The TPS RDT&E costs were calculated on the basis of costs previously estimated for basic development, tools, design and test
- The investment costs were calculated on the basis of the unit costs determined by the detail estimate made previously

- STAGING ALTITUDE = 311,000 FT
- STAGING VELOCITY = 10,690 FPS
- n_Z = 5 g MAX
- W/S_{ENTRY} = 47 PSF

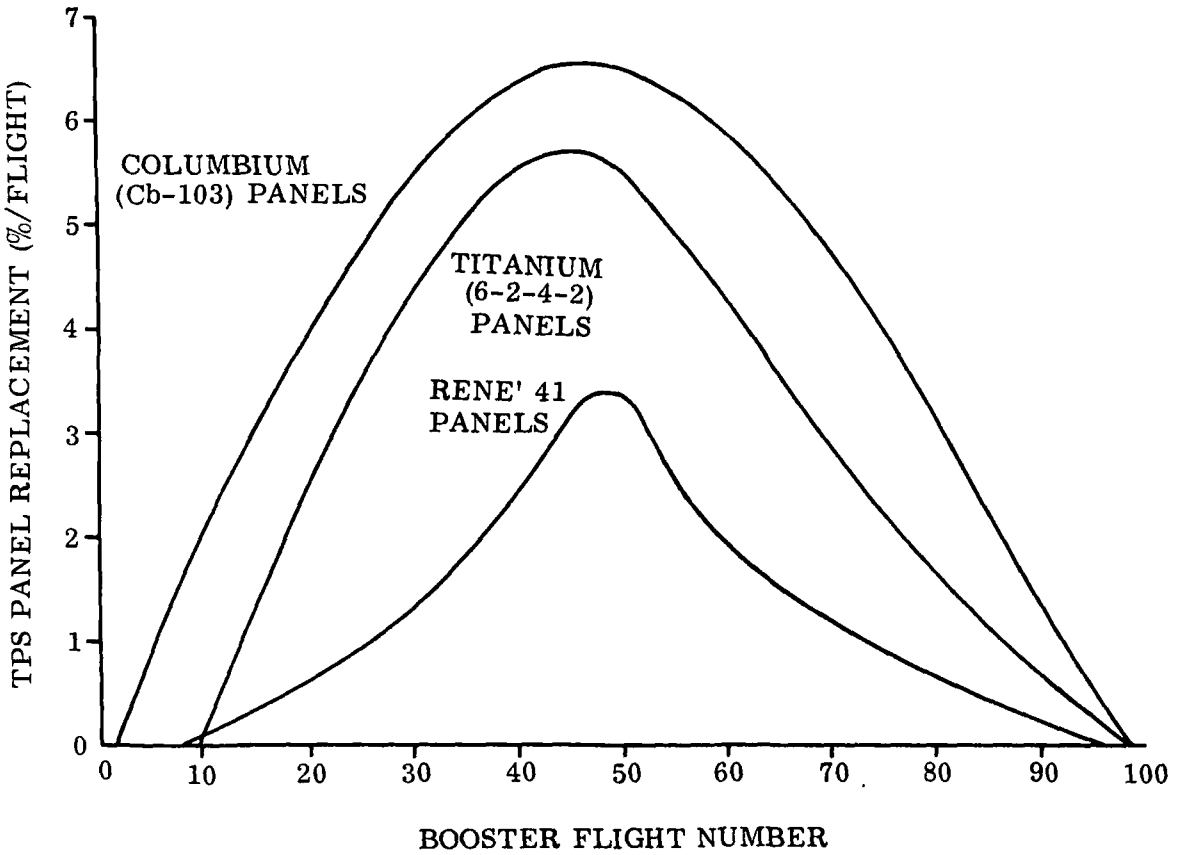


Figure P-6. Booster TPS Panel Replacement Schedule

- Operations costs were calculated on the basis of the cost per square foot previously estimated. An example of such unit costs are shown in Figure P-7 for a particular booster
- The costs for one vehicle operated for 100 flights was obtained by adding the RDT&E, investment and operations costs calculated.

P. 2. 7 Determination of Booster System Unit and Total Costs Without the TPS System

The third step is to determine the cost of the 31 Booster iterations being studied complete with RDT&E, investment and operations costs for all subsystems except the TPS.

The following steps were made to obtain the Booster minus TPS system costs:

- The cost of each subsystem was calculated using the Booster cost estimating methods and maintaining the booster performance constant
- The subsystem weights were determined for the subsystems for which costs were calculated
- Cost of propellants were estimated and added to the other costs to obtain the total systems cost
- Unit costs for the Boosters were obtained by dividing the total subsystem costs for the various boosters studied by the dry weight of the booster subsystems without the TPS.

P. 2. 8 Determine Total Cost of the Orbiter

The fourth step in estimating the total system cost was to determine the cost of the Orbiter. The cost of the Orbiter was established October 22, 1970 and a curve developed which provides the Orbiter cost as a function of the Orbiter liftoff weight. The baseline vehicle at that time weighed 760, 230 lb and cost $13, 838, 000.

P. 2. 9 Total Orbiter/Booster System Cost Determination

The final step in estimating the total Orbiter/Booster system costs for the Boosters used in the heat sink study is the calculation and summation of the 31 study

- Staging Velocity = 10,690 FPS
- Staging Altitude = 311,000 Ft
- Max Normal Load Factor = 5 g
- Entry Wing Loading = 47 PSF

TPS Material Coverage

- Cb-103 16,940 Ft^2
- Rene' 41 7,760 Ft^2
- Titanium 13,080 Ft^2

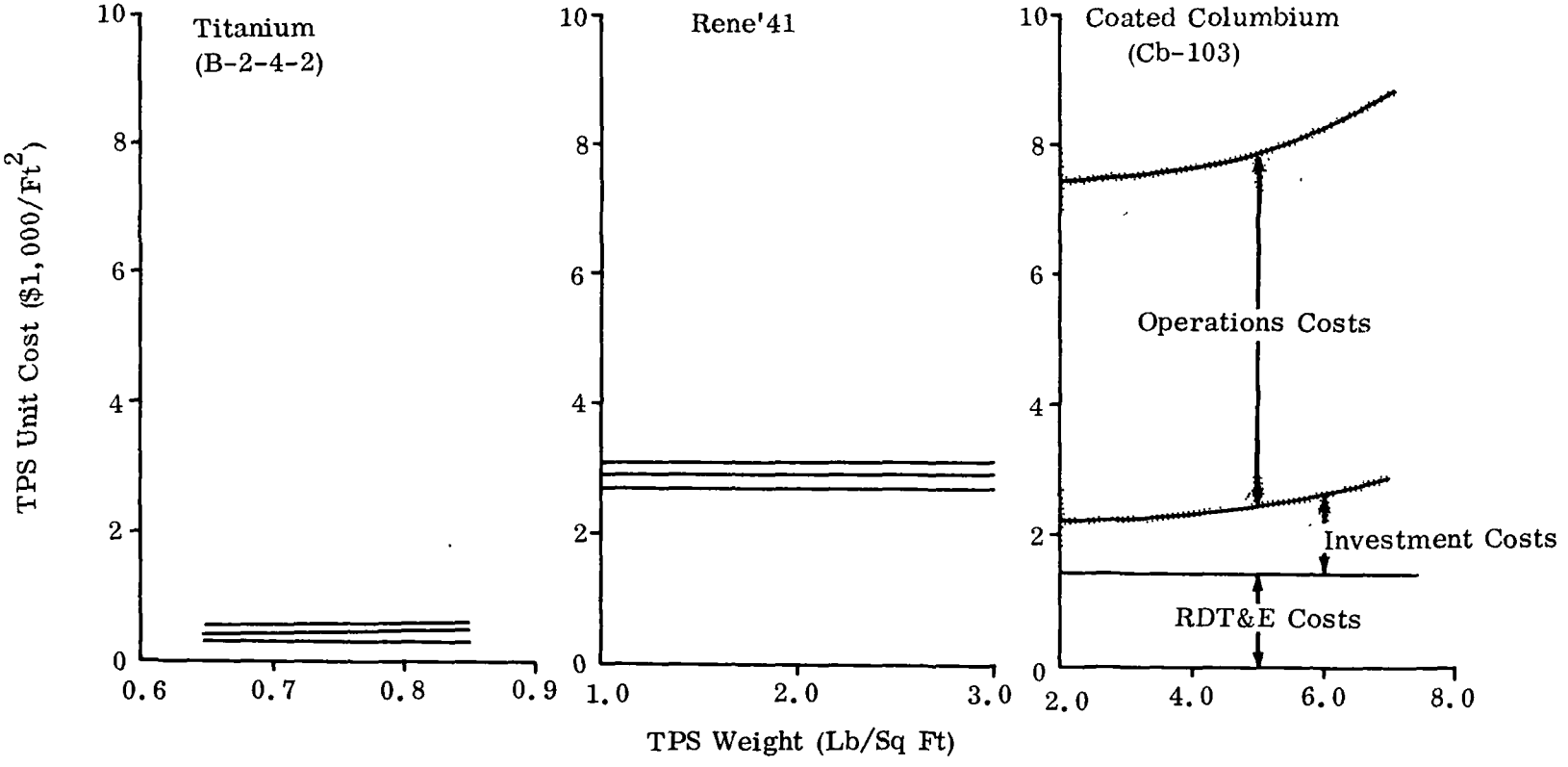


Figure P-7. Reradiation TPS Unit Costs

Boosters, TPS cost, Booster costs and the Orbiter/Booster system costs. The following steps were taken to obtain the total system costs:

- Iterate TPS and Booster weight and cost on the basis of revised vehicle size to maintain constant system performance
- Escalate the cost of each Booster and its TPS by the ratio of the escalated booster inert weight to the trending data weights
- Determine the Orbiter liftoff weight required for each Booster and obtain the total Orbiter system cost from the trending data curve
- Combine the calculated costs of the escalated TPS, Booster systems, without the TPS and the Orbiter system. This cost is for one vehicle and cost of 100 flights
- The final step is to increase the system cost to cover the number of vehicles and the number of flights specified for the program to obtain the total program cost

The system costs were estimated on three levels of detail. The TPS costs were estimated at the component level. Booster costs were determined by estimating the subsystem costs for RDT&E, investment and operations. Orbiter costs were obtained from a curve showing orbiter system cost for various OLOWs.

Appendix Q

COST/DESIGN PERFORMANCE MANAGEMENT SYSTEM

Q.1 INTRODUCTION

The objective of the Space Shuttle Program is to design a low cost space transportation system --- the minimum cost system which will achieve mission objectives.

In the present contract phase, consideration is given to the parameters of a conceptual design. By using cost modeling techniques based on historical data from similar or related programs, a planned program is evaluated and a baseline established. As design parameters are further refined, cost estimates are also modified and compared with the baseline as a basis for Study decisions.

Similarly, NASA may evaluate and compare its own target, budget, or baseline estimate to that of the contractor (or competitors), to establish a basis for program decisions. As the program evolves, thru Phase B and into Phases C and D, the design is actualized and actual costs are brought into the control system. To meet minimum cost objectives a system must be established to monitor program estimates, explain changes in estimates, stimulate cost reduction and compare specific estimates with cost targets derived from the NASA Total Cost Objective or "Bogey."

Q.2 GUIDELINES FOR COST/DESIGN PERFORMANCE SYSTEM DEVELOPMENT

In considering the design of a management system to realize cost objectives, certain guidelines must be established.

Typical examples are:

(1) Quick response.

(2) Priority to high cost or time-critical items.

(3) Surveillance of critical skills, facilities, or scarce resources.

(4) Formal consideration of cost in all design tradeoffs.

(5) Baseline estimates are defined by:

(a) Work Breakdown Structure.

(b) Weight Statement.

(c) Master Schedule.

(d) Specification Handbook.

(6) The system must document all changes.

(7) Costs are broken down to subdivision of work level on Work Breakdown Structure, and are accounted for by subsystem and functional management.

(8) The system must be comprehensive and flexible permitting a smooth transition from Phase B activity to Phases C & D.

Q.3 ELEMENTS OF THE SYSTEM

To assure performance, a cost/design management system must consist of a baseline, a target, a self-stimulating cost reduction system, a system for reporting all cost tradeoff actions (including those which are disapproved), and a program management review cycle for evaluation of impact of cost/design tradeoffs on areas beyond the responsibility of system or functional managers.

The system is controlled and implemented by the Program Management Office, under the direction of the Design/Cost Management Office.

The procedures used are:

(1) Design/Cost Tracking and Reporting Procedure

(2) Tradeoff Tracking and Reporting Procedure

(3) Independent Cost Reduction Procedure

Within the Tradeoff Procedure is a subroutine for weight versus cost tradeoff for each subsystem. This requires weight as well as cost objectives and the identification of the weight-cost trade which results in equivalent total program cost.

Q.4 BASELINE COST TARGETS

The first step in implementation of the Cost/Design Performance Management System requires the establishment of baseline cost targets.

Baseline cost targets are obtained as follows:

(1) Parametric estimates are prepared for the baseline configuration.

(2) Parametric estimates are detailed to subsystem level. Test, support and other items are also detailed to this level of the Work Breakdown Structure.

(3) Parametric estimates are broken down into subdivisions of Work.

(4) Parametric estimates are broken down into Element of Cost.

(5) Estimates as detailed above are reviewed with Subsystem Managers, Functional Managers and the Program Manager.

(6) Upon approval by the Program Manager, the above estimates, in total, constitute the Baseline Cost Estimate.

(7) The Program Cost Target is received from NASA.

(8) As a first approximation, the target is allocated to subsystem (and other Work Breakdown Structure items at the subsystem level) on a prorata basis, i.e., the percentage relationship of target cost to the Baseline estimate.

(9) Each subsystem is reviewed to determine the degree to which cost is controllable by the Subsystem Manager. For example, the cost of off-the-shelf items and raw material is relatively fixed. Burden costs distributed to each subsystem are not controllable to the same degree as labor rates.

(10) Preliminary cost targets are adjusted to reflect best judgment of a "balanced" target structure - each manager should have approximately the same probability of achieving his assigned target.

(11) When approved by the Program Manager, the adjusted targets, in total, comprise the Program Baseline Targets.

(12) As design/cost effort proceeds, the targets are further adjusted to reflect program changes and maintain an equitable balance. Various factors justify target adjustments, for example, customer-directed additions or deletions of subsystem components including transfer of components between subsystems or the transfer of responsibility for components from one Associate Contractor to another.

Q.5 SUMMARY

The Primary Space Shuttle Program Objective is:

(1) An operational mode which will permit a significant reduction below present operational costs.

(2) A flexible capability to support a variety of payloads and missions.

(3) Transport for passengers and cargo approximating airline type operations as a goal.

(4) A fully or partially reusable system with a high launch rate capability and short turnaround and reaction times compatible with rescue missions.

NASA desires discrete cost reductions from the contractor's basic estimate tied to discrete changes - management and technical. The contractor is to propose innovative approaches to attainment of these objectives:

- Vehicle design
- Program requirements
- Changes to Program Management techniques

- Technical requirements
- Contractor procedures and management approach

The contractor is to use cost as a prime indicator of merit in tradeoffs commensurate with adequate performance.

To implement this requirement the contractor shall develop a plan for a Cost/Design Performance Management System defining the responsibilities and authorities for effective execution and the techniques and procedures to be utilized. The cost implications of design, development, test and operations activities shall be included in the shuttle design and tradeoff decisions. The current cost estimates for the system elements shall be related to the total cost objectives including a breakdown of both the estimate as well as the cost objective into subsystem and cost elements.

NASA will supply two elements of this plan, the Phase C/D Work Breakdown Structure and the Total Cost Objectives. In implementing the plan, the Contractor will review the baseline estimate with NASA to achieve a clear understanding as to the realism of the estimate, assess the feasibility of the Total Cost Objective and make recommendations to NASA as to potential changes in study control requirements which will minimize cost. A schematic of the main elements of the system is given in Figure Q-1.

DESIGN/COST TRACKING AND REPORTING PROCEDURE

Purpose:

To maintain visibility of Space Shuttle Team progress in developing a minimum cost system.

Description:

This procedure covers the activities of:

- Program Baseline Definition
- Design/Cost Change Control
- Reporting

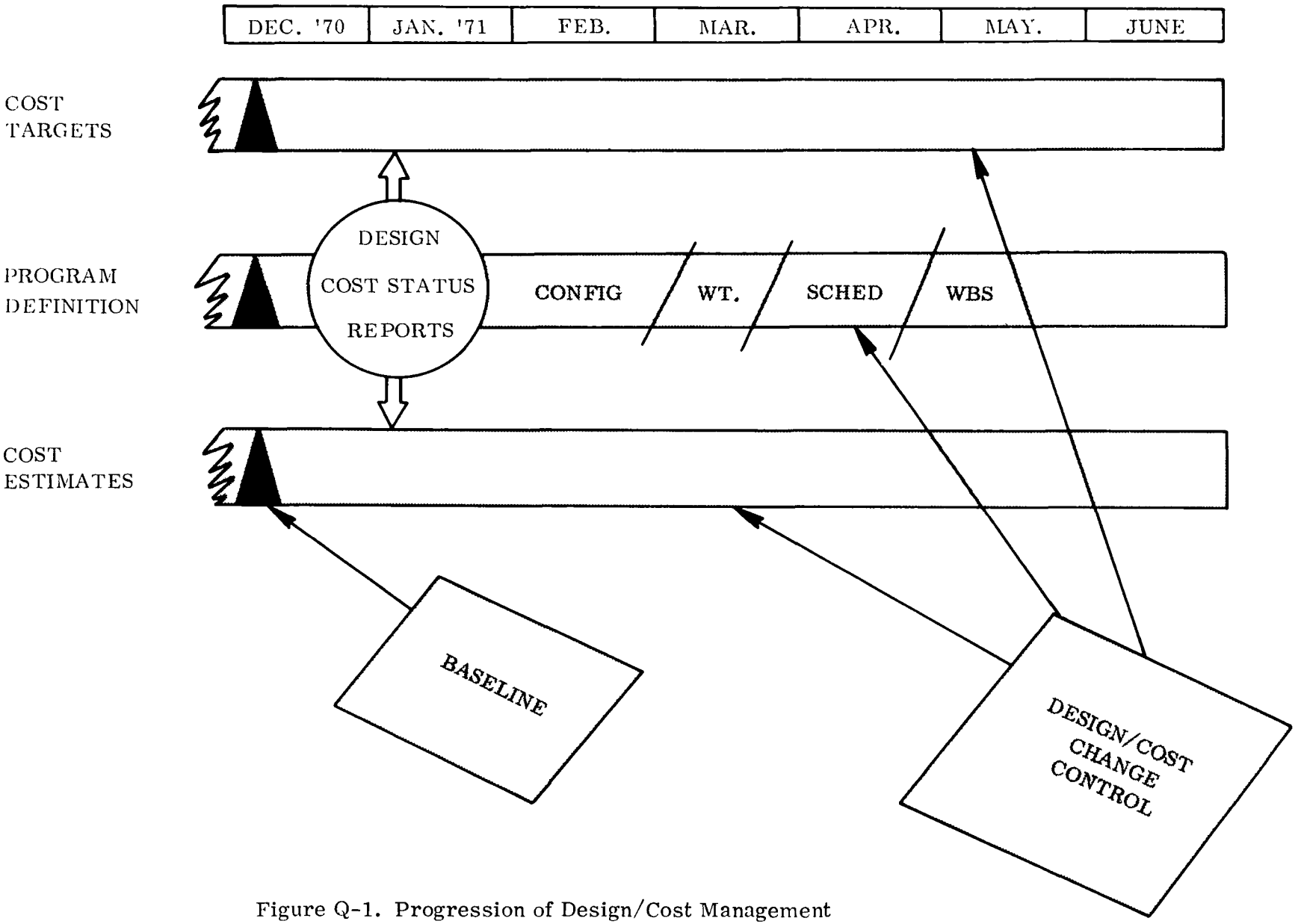


Figure Q-1. Progression of Design/Cost Management

Program Baseline

The Program Baseline is defined by the following program baseline documents:

- Technical Definition
  - Specification Handbook
  - Weight Statement
- Program Definition
  - Work Breakdown Structure
  - Master Schedule
- Baseline Cost
  - Cost Estimate by Subdivision of Work at Subsystem Level
- Baseline Cost Target
  - Cost Targets by Subdivision of Work at Subsystem Level

Design/Cost Change Control

The Program Baseline is updated by the Design/Cost Changes Control System which accepts and accounts for all changes to the Baseline Definition Documents listed above.

A formal revision to any one of the above documents is recorded and numbered in the Design/Cost Change Record.

Certain revisions which arise from normal design and program planning activities are reviewed by the Design/Cost Management Office to determine whether cost analysis is required. Minor changes in weight or schedule may be within confidence limits of the existing estimates.

Other revisions will be implemented as the result of cost reduction recommendations or cost tradeoff activities. The control number for these changes will cross reference changes to baseline documents.

All significant changes in technical and program parameters shall be cross-referenced to changes in cost through the Change Record Book.

Likewise, all changes in cost shall be cross referenced to technical and program changes.

In the event significant technical and program changes produce offsetting cost factors and the net cost impact is negligible, a suitable explanation shall be referenced in the Change Record Book.

If there is significant change in cost factors rates, etc., without an accompanying change in technical and program characteristics, a suitable explanation shall be referenced in the Change Record Book. All changes in cost targets, such as addition or deletion of equipment, reallocation due to subsystem change, etc., shall be recorded in the Change Record Book. A flow chart illustrating the steps in accomplishing this procedure is shown in Figure Q-2; a sample format for requesting changes is given in Figure Q-3.

Reporting

By continuously updating the program baseline documents, the preparation of status reports will be relatively simple.

The updated program cost estimate is compared with the updated cost target at subsystem level and for each subdivision of work.

Reasons for change and prospects for further cost reductions are discussed by Subsystem Managers. The report is issued by the Design/Cost Management Office and following Management review and approval becomes part of the contractual reporting system.

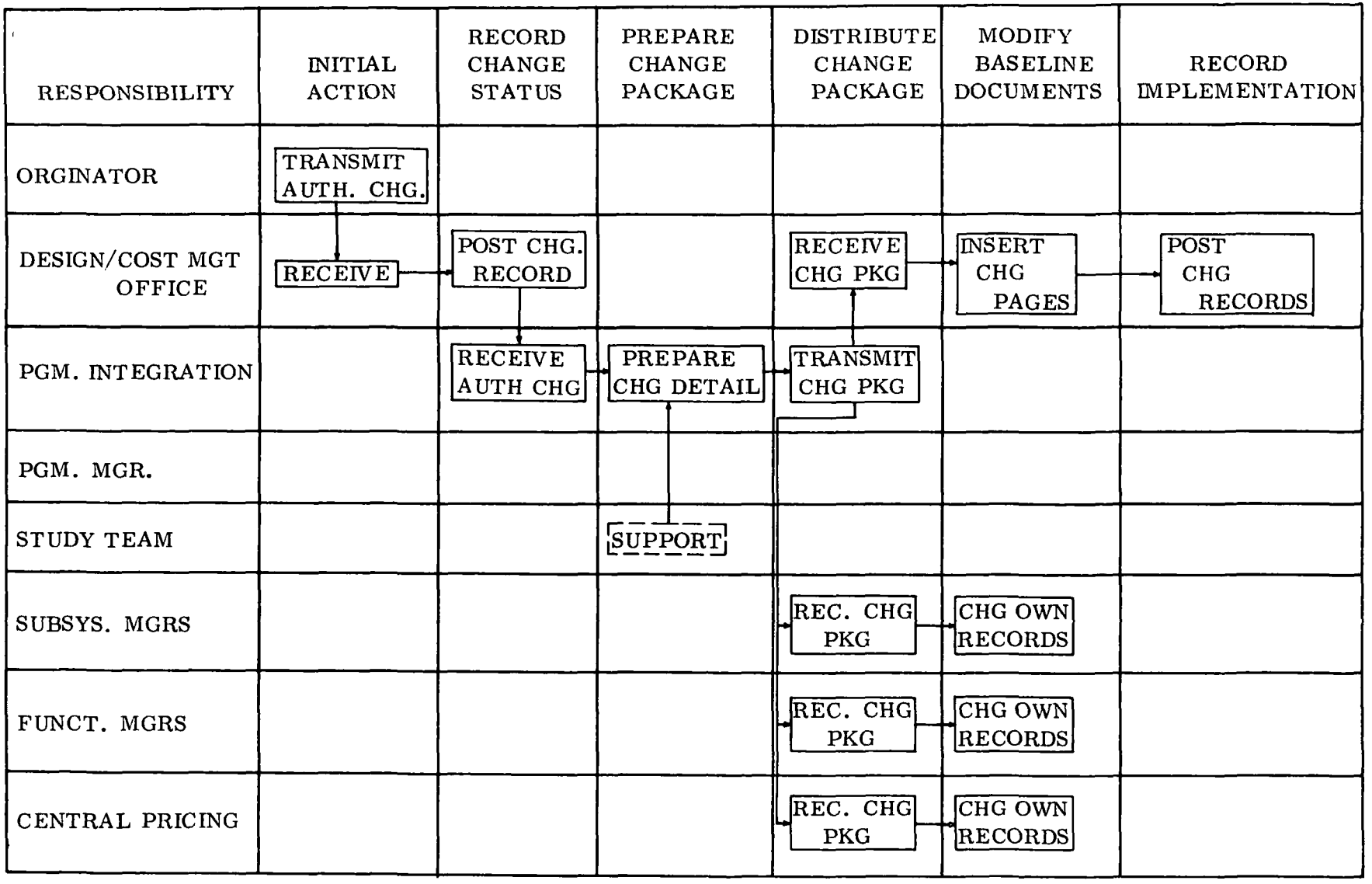


Figure Q-2. Design/Cost Change Procedure

REQUEST FOR CHANGE TO COST ESTIMATE/TARGET

DATE _____

REQUESTED BY _____ CONTROL NO. _____
(NAME) (DEPT/GP)

WBS ITEM _____ SPEC HDBK. REF. ____

SUBDIVISION OF WORK	COST WAS		CHANGE TO	
	HOURS	DOLLARS	HOURS	DOLLARS
DESIGN				
TOOLING				
MANUFACTURING				
TEST				
OTHER				
TOTAL				

REASON FOR CHANGE:

APPROVED:

Figure Q-3. Request for Change to Cost Estimate/Target

INDEPENDENT COST REDUCTION PROCEDURE

Purpose

To solicit cost reduction recommendations, provide for the orderly review, analysis, approval and implementation of recommendations submitted.

Initial Recommendation

Cost reduction recommendations are initiated by any member of the Shuttle Study Organization. All personnel are expected to implement cost reduction ideas which fall within their area of responsibility; however, use of the formal recommendation procedure will serve as a means of:

(1) Assuring that the effect of the reduction is considered in program cost estimates.

(2) Communicating cost reduction ideas to other members of the Shuttle Team for use as appropriate.

(3) Communicating to Program Management and to the NASA the progress in developing a minimum cost program.

(4) Coordinating cost reductions and technical or program changes within the Design/Cost Management System.

A standard form is provided for submittal of cost reduction recommendations. It is to be submitted concurrently to the immediate supervision of the originator and to the Design/Cost Management Office.

The Design/Cost Management Office will review the recommendation for clarity, accuracy and completeness, obtain supplementary data if required, and present to Program Management for approval.

If further analysis is required, Program Management will assign a team of cost review specialists to conduct necessary studies and evaluation. The team will include program control, pricing and operating department personnel needed to cover all technical, programmatic and cost aspects of the recommendation. Upon

conclusion of the study, the Design/Cost Management Office will arrange presentation for Program Manager approval.

Implementation

When the recommendation is approved, the Design/Cost Management Office will take necessary steps to direct implementation by those concerned in technical, programmatic and cost areas.

Documentation

A current record of cost reduction recommendations will be maintained by the Design/Cost Management Office. A status board for approved recommendations will be maintained in the Control Room. The results and conclusions are recorded in a Cost Reduction Workbook.

Processing of Changes

Results of recommendations implemented are processed through the Design/Cost Change Control System. Change numbers are assigned and reference is made to the Cost Reduction Workbook permitting tracking and justification of all technical program, and cost changes that flow through the Cost Reduction System. A flow chart illustrating steps in accomplishing this procedure is provided in Figure Q-4; a format for submission of cost reduction recommendations is given in Figure Q-5.

TRADEOFF TRACKING AND REPORTING PROCEDURE

Purpose

The purpose of this procedure is to identify system tradeoffs so that they can be planned, coordinated, executed and the results documented in an efficient manner to assure that all affected parts of the system and program are considered, including cost and schedule, and to insure that an integrated summary of the results is provided at the completion of the tradeoff study.

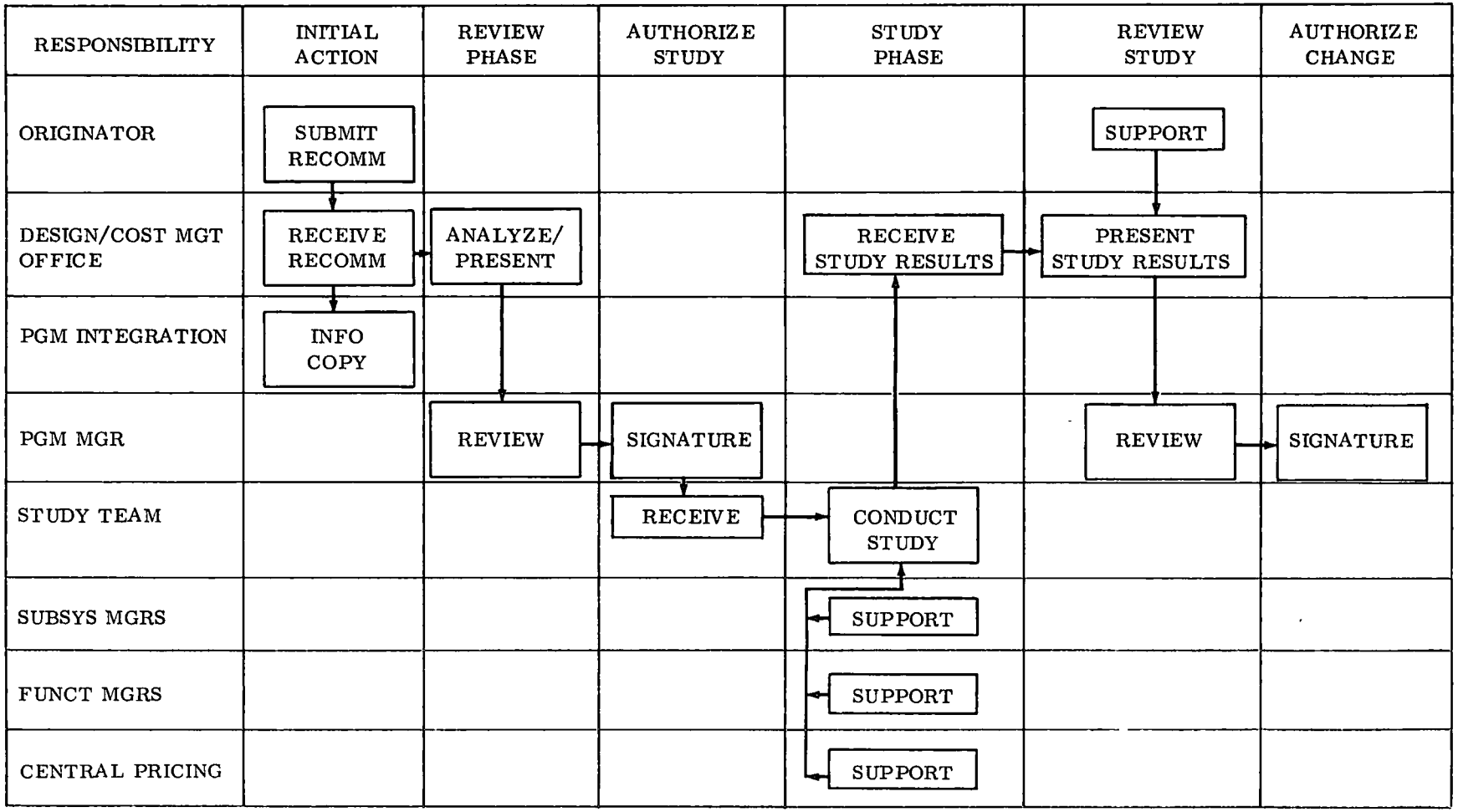


Figure Q-4. Cost Reduction Study Control

ORIGINATOR _____ DATE _____
(NAME) (DEPT/GP)

CONTROL NO. _____

WBS ITEM _____ SPEC HDBK REF _____

DESCRIPTION OF CHANGE			
ATTACHMENTS			
INTERFACES			
PROBABLE SAV'GS & RATIONALE			
REVIEWED BY _____	NEXT ACTION _____	FINAL DISPOS'N _____	

Figure Q-5. Cost Reduction Recommendation Design-to-Cost Sheet

Initial Identification

It is the responsibility of the individual study managers to identify and plan the tradeoffs identified in the initial study planning effort. The study managers should complete the Tradeoff Study Cost form and submit it to Program Integration. After the initial planning phase anyone may request further tradeoff studies by submitting a completed form to Program Integration. The request will be reviewed with the study managers by Program Integration to determine if it is within the scope of the present study effort and to obtain Program Management Approval.

Implementation

Once the form is completed and approved, it will contain all of the required tasks and responsibilities for execution, including the form of the results; if necessary, additional information is attached to the request. It is the responsbility of each Manager to plan and execute his phase of the tasks in accordance with normal task planning and scheduling, including identifying tasks on the Control Room Planning and Scheduling Boards. Program Integration will review progress to provide integration of study efforts and assure proper attention to the cost and schedule aspects.

Documentation

A record of the tradeoff study requests and their current status will be maintained by Program Integration. A display board of Approved Tradeoff Studies will be maintained in the Control Room. The results and conclusions will be incorporated in a Tradeoff Study Workbook.

It is anticipated that the results of one tradeoff study may result in the initiation of a second tradeoff study. To relate these studies to one another the follow-on study should use the original study number with the addition of a sequential dash number.

Special Tradeoff Studies

Because of the special sensitivity of the Space Shuttle, it is necessary to perform a weight-cost tradeoff study for each subsystem to achieve a minimum total program cost solution. Initially all subsystems will have a weight and cost objective identified. The breakeven weight-cost tradeoff which results in equivalent total program costs will be determined and, in this way, each alternative subsystem design can be judged to more closely achieve or better the intent of the combined weight and cost objectives in terms of total program cost.

Processing of Changes

Results of studies implemented are transmitted to the Design/Cost Management Office for processing through the Design/Cost Change Control System. Change Numbers are assigned and reference is made to the Tradeoff Study Workbook permitting tracking and justification of all technical program and cost changes that flow through the tradeoff system. A flow chart illustrating steps in accomplishing this procedure is provided in Figure Q-6; a sample format for requesting tradeoff studies is shown in Figure Q-7.

DATE _____

REQUESTED BY _____ CONTROL NO. _____
(NAME) (DEPT/GP)

STUDY TITLE _____

PURPOSE	
TASK DESCRIPTIONS & RESPONSIBILITIES (INCL. NAMES & ORG'S)	
RESULTS REQUIRED	
APPROVALS (AS APPROPRIATE)	CONCEPT MGR _____ OPNS & TEST MGR _____ ENG'R'G MGR _____ PGM INTEG MGR _____

Figure Q-6. Tradeoff Study Request

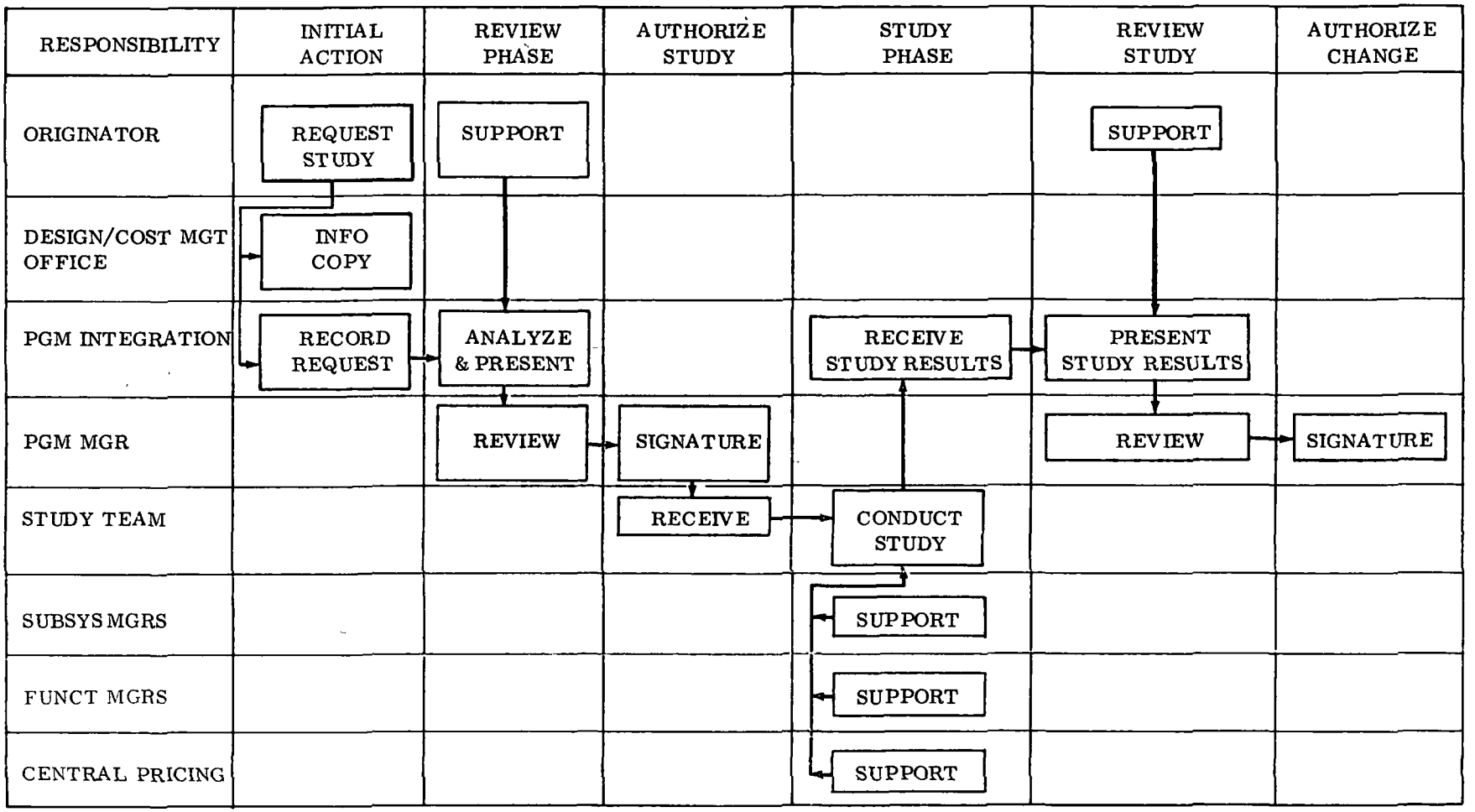


Figure Q-7. Tradeoff Study Control

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BETHPAGE, NEW YORK 11714